

Award Number:
W81XWH-11-2-0020

TITLE:
USASOC Injury Prevention/Performance Optimization Musculoskeletal Screening Initiative

PRINCIPAL INVESTIGATOR: John Abt, PhD, ATC

CONTRACTING ORGANIZATION: University of Pittsburgh
Pittsburgh, PA 15213-2303

REPORT DATE: September 2015

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release; distribution unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE				<i>Form Approved OMB No. 0704-0188</i>	
<small>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</small>					
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To) 25Oct2010 - 24Jun2015	
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) John Abt; Scott Lephart; Timothy Sell; Mita Lovalekar; Kim Beals; Pete Benson; Russ Kotwal; Jeffrey Morgan; Shawn Kane email: john.abt@uky.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 124	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)

Table of Contents

Introduction	2
Body.....	2
Key Research Accomplishments Since Start of Project.....	2
Administrative	49
Personnel.....	49
Human Subject Protections	49
Reportable Outcomes.....	50
Conclusions	50
References	51
Appendices	52

Introduction

Unintentional musculoskeletal injuries limit tactical readiness, shorten the active duty life cycle, and diminish the quality of life of the personnel after military service. Many of these injuries are preventable or their severity mitigated through implementation of demand-specific physical training for injury prevention and performance optimization developed through scientific research. At the request of the Command Surgeon from the United States Army Special Operations Command (USASOC), this research sought to support development of USASOC's Tactical Human Optimization, Rapid Rehabilitation, and Reconditioning (THOR3) program by identifying the priorities necessary for enhancement and change in the current physical training program. Consistent with an injury prevention and performance optimization model implemented by the University of Pittsburgh and previously developed from over 20 years of research with elite athletes and Special Forces, this research was designed address the cause and prevention of musculoskeletal injury and detriments to optimal performance by identifying suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristics that are task and demand-specific to the Special Forces soldier.

Body

Project Overview

This collaborative research was modeled after our research with Naval Special Warfare and was submitted to program announcement W81XWH-09-DMRDP-ARATDA at the request of the Command Surgeon of the United States Army Special Operations Command (USASOC) to support development of USASOC's Tactical Human Optimization, Rapid Rehabilitation, and Reconditioning (THOR3) program and identify the priorities necessary for improvement and growth in their current physical training program. The overall objective of this four phase research initiative was to provide the scientific arm by which USASOC would refine its THOR3 program. It was our intent the research will result in a validated THOR3 program that reduces unintentional musculoskeletal injury and improves physical and tactical readiness. The current research under this award was to test the first three phases of research and was hypothesized to result in identified injury characteristics and risk factors of the USASOC Operator and a validated THOR3 program which alters injury risk characteristics. This research addressed the project/tasks as outlined in Funding Opportunity Number: W81XWH-09-DMRDP-ARATDA (Operational Health and Performance- Fundamental Mechanisms of Training and Operational Injury).

Key Research Accomplishments Since Start of Project

Injury Epidemiology of U.S. Army Special Operations Forces

Musculoskeletal injuries have long been a problem in general purpose forces, yet anecdotal evidence provided by medical, human performance, and training leadership suggests musculoskeletal injuries are also a readiness impediment to Special Operations Forces (SOF). The purpose of this study was to describe the injury epidemiology of SOF utilizing self-reported injury histories. Data were collected on 106 SOF (Age: 31.7 ± 5.3 years, Height: 179.0 ± 5.5 cm, Mass: 85.9 ± 10.9 kg) for one year prior to the date of laboratory testing and filtered for total injuries and those with the potential to be preventable based on injury type, activity, and mechanism. The frequency of musculoskeletal injuries was 24.5 injuries/100 subjects/year for total injuries and 18.9 injuries/100 subjects/year for preventable injuries. The incidence of musculoskeletal injuries was 20.8 injured subjects/100 subjects/year for total injuries and 16.0 injured subjects/100 subjects/year for preventable injuries. Preventable musculoskeletal injuries comprised 76.9% of total injuries. Physical training (PT) was the most reported activity for total/preventable injuries (PT Command Organized: 46.2%/60.0%, PT Non Command Organized: 7.7%/10.0%, Physical Training Unknown: 3.8%/5.0%). Musculoskeletal injuries impede optimal physical readiness/tactical training in the SOF community. The data suggest a significant proportion of injuries are classified as preventable and may be mitigated with human performance programs. **Complete description of key findings may be found in Appendix 1.**

Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Operators

Musculoskeletal injuries are a significant burden to United States Army Special Operations Forces. The advanced tactical skill level and physical training required of Army Special Operators highlights the need to optimize musculoskeletal characteristics to reduce the likelihood of suffering a recurrent injury. The purpose of this study was to identify the residual impact of previous injury on musculoskeletal characteristics. Isokinetic strength of the knee, shoulder, and back and flexibility of the shoulder and hamstrings were assessed as part of a comprehensive human performance protocol and self-reported musculoskeletal injury history was obtained. Subjects were stratified based on previous history of low back, knee, or shoulder injury and within-group and between-group comparisons were made for musculoskeletal variables. Knee injury analysis showed no significant strength or flexibility differences. Shoulder injury analysis found internal rotation strength of the healthy subjects (H) was significantly higher compared to the injured (I) and uninjured (U) limbs of the injured group (H: 60.8 ± 11.5 %BW, I: 54.5 ± 10.5 %BW, $p = 0.05$, U: 55.5 ± 11.3 %BW, $p = 0.014$). The external rotation/internal rotation strength ratio was significantly lower in the healthy subjects compared to the injured and uninjured limbs of the injured group (H: 0.653 ± 0.122 , I: 0.724 ± 0.121 , $p = 0.026$, U: 0.724 ± 0.124 , $p = 0.018$). Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (I: $111.6 \pm 9.4^\circ$, U: $114.4 \pm 9.3^\circ$, $p = 0.008$). The back injury analysis found no significant strength differences between the healthy and injured groups. Few physical differences existed between Operators with prior knee or back injury. However, Operators with a previous history of shoulder injury demonstrated significantly less shoulder strength than uninjured Operators as well as decreased shoulder flexibility on the injured side. All Operators, regardless of prior injury must perform the same tasks; therefore a targeted injury, rehabilitation/human performance training, specifically focused on internal rotation strength and tightness of the posterior capsule, may help reduce the risk for recurrence of injury. Operators presenting with musculoskeletal asymmetries and/or insufficient strength ratios may be predisposed to musculoskeletal injury. **Complete description of key findings may be found in Appendix 2.**

Physical and Performance Characteristics Related to Unintentional Musculoskeletal Injury in United State Army Special Forces: A Prospective Analysis

Musculoskeletal injuries are serious and often an under recognized concern within military forces. Recent epidemiological data collected on US Army Special Forces Operators demonstrated that 76.9% of injuries were preventable musculoskeletal injuries and support the use of an injury prevention and performance enhancement program. However, population specific characteristics related to injury must first be identified. The purpose of this study was to determine which characteristics are predictive of musculoskeletal injury and may be useful for screening procedures in US Army Special Forces Operators. A total of 95 US Army Special Forces Operators participated in this study (age = 32.7 ± 5.1 years, height = 179.8 ± 6.9 cm, weight = 89.9 ± 12.7 kg). Laboratory testing included body composition, aerobic and anaerobic capacity, upper and lower body strength and flexibility, balance, and biomechanical testing. Injury data were captured for a period of twelve months following laboratory testing. Injury frequencies and cross-tabulations were calculated to evaluate the relationships between measured physical characteristics and injury proportions. Odds ratios were calculated to further evaluate the usefulness of each physical characteristic as a risk factor for injury. Injured operators demonstrated significantly less trunk strength and knee position during landing in comparison with uninjured operators. Trunk strength was also diminished in the sub-group of spine-injured operators. Knee position at initial contact was also significantly less in operators who experienced a lower extremity injury and those who experienced a spine injury. Operators who fell into the bottom 25th percentile on knee, shoulder and/or trunk strength were over two times more likely to have sustained an injury. This study showed that decreased knee, shoulder, and trunk strength are risk factors for subsequent musculoskeletal injury in Army Special Forces operators. The accumulation of two or more of these risk factors results in higher proportions of injured operators. Injury prevention initiatives in Special Forces should focus on identifying and correcting deficits in knee, shoulder, and trunk strength, aerobic capacity, and knee position during landing. Specific individualized training programs targeting these characteristics are necessary to maintain force health and readiness. **Complete description of key findings may be found in Appendix 3.**

Physical Readiness and Musculoskeletal Injury Prevention in United States Army Special Forces Operators

Unintentional musculoskeletal (MSK) injuries continue to be a significant issue for the United States Army Special Operations. There is a need to find ways to identify and modify risk factors to injuries to sustain the careers of Operators as well as to maximize physical performance on job specific tasks. The purpose of this study was to examine the relationship of physical readiness rankings to MSK injury risk factors in US Army Special Forces Operators. A total of 75 Operators participated in this study. Physiological testing included measures of body composition, muscular strength, aerobic capacity and anaerobic power. Individuals also completed a self-reported MSK injury history that covered the span of their military career up to the point of testing. Operators were assigned a physical readiness ranking based on their combined performance on all laboratory testing. Data was then analyzed two separate ways. The first with those ranked in the top 10% being classified as Group 1 with all others in Group 2. The second method was dividing the sample into quintiles based on their overall ranking. Significant differences were noted between groups and quintiles for the majority of performance testing, but not for body composition. Physical readiness ranking did not seem to have a direct impact on injury rates, however the variation within the injury data was quite large, which may have played a role. The present study was one of the first to provide a physiological description of a US Army SF Operator and shed light on possible injury risk factors that can be modified through proper training. **Complete description of key findings may be found in Appendix 4.**

Subject Demographics

	Age (Years)	Height (Inches)	Weight (Pounds)
USASOC (All)	32.0 ± 6.9	70.5 ± 2.6	187.4 ± 25.3
18 Series (3/5 SFG)	32.0 ± 5.3	70.5 ± 2.3	187.7 ± 23.3
SWCS (18 Series)	36.8 ± 8.1	70.5 ± 2.5	187.6 ± 22.9
Q-Course	28.6 ± 3.2	72.1 ± 2.3	184.5 ± 23.0
Pre Q-Course	23.3 ± 2.4	69.7 ± 3.9	175.5 ± 30.5
Support	34.5 ± 6.3	70.9 ± 2.5	192.4 ± 24.9
Other	36.0 ± 7.0	70.3 ± 2.3	193.3 ± 25.6

Musculoskeletal, Physiological, and Biomechanical Profiles

Subjects enrolled in the study underwent a comprehensive human performance assessment for injury prevention and optimal physical readiness to evaluate biomechanical, musculoskeletal, physiological, and nutritional characteristics relative to injury and performance. Specific testing included musculoskeletal strength and flexibility, balance, aerobic capacity and lactate threshold, anaerobic power and capacity, body composition, movement patterns during functional (tactical) tasks, nutritional history, and injury history. The following section details the results of data collection for musculoskeletal (strength, flexibility, balance), physiological, and biomechanical characteristics.

Shoulder Internal Rotation (IR) and External Rotation (ER) Strength

Testing Methodology:

Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)

5 repetitions

Average peak torque/body weight (BW)

Purpose: Examine rotator cuff strength

Background: Proper IR and ER rotator cuff strength is critical for the performance of demanding overhead tasks and maneuvers involving the upper extremity, and is critical for the prevention of shoulder injury. The glenohumeral joint is dependent upon the health of the rotator cuff as a source of dynamic joint stabilization. Deficiencies in strength or reciprocal balance of the rotator cuff musculature will predispose the shoulder joint to altered kinematics, leading to acute and/or chronic joint instability, impingement syndromes, and rotator cuff tears. Further, shoulder IR and ER strength testing consistently detects persistent and potentially dangerous rotator cuff weakness after previous injury.

Data and Results:

RIGHT

	IR (% BW)	ER (% BW)	ER/IR (Ratio)
Top 10th %tile 3SFG	78.6	49.3	--
Top 25th %tile 3SFG	68.1	45.4	--
50th %tile 3SFG	61.3	40.0	--
Bottom 25th %tile 3SFG	52.2	36.1	--
Athlete*	53.0 ± 12.0	40.0 ± 10.0	0.77 ± 0.16
Triathletes	64.3 ± 9.7	46.5 ± 6.9	0.73 ± 0.09
USASOC (All)	56.8 ± 12.3	38.7 ± 7.0	0.70 ± 0.15

18 Series (3/5 SFG)	60.8 ± 12.8	41.0 ± 7.2	0.70 ± 0.15
SWCS (18 Series)	55.8 ± 7.2	38.2 ± 5.8	0.70 ± 0.14
Q-Course	52.7 ± 12.4	38.7 ± 5.1	0.78 ± 0.25
Pre Q-Course	56.9 ± 9.8	38.0 ± 5.0	0.68 ± 0.10
Support	50.4 ± 13.5	36.2 ± 6.0	0.74 ± 0.15
Other	53.8 ± 10.6	35.7 ± 6.3	0.67 ± 0.14

LEFT

	IR (% BW)	ER (% BW)	ER/IR (Ratio)
Top 10th %tile 3SFG	79.1	48.9	--
Top 25th %tile 3SFG	64.9	43.8	--
50th %tile 3SFG	57.2	39.1	--
Bottom 25th %tile 3SFG	49.4	35.9	--
Athlete*	53.0 ± 12.0	40.0 ± 10.0	0.77 ± 0.16
Triathletes	65.5 ± 13.6	44.5 ± 7.3	0.69 ± 0.12
USASOC (All)	55.5 ± 11.9	37.3 ± 6.8	0.68 ± 0.12
18 Series (3/5 SFG)	58.7 ± 12.6	40.3 ± 7.1	0.70 ± 0.12
SWCS (18 Series)	56.9 ± 8.5	37.9 ± 4.5	0.68 ± 0.10
Q-Course	54.0 ± 7.6	40.5 ± 8.0	0.76 ± 0.10
Pre Q-Course	55.1 ± 10.5	34.2 ± 4.7	0.62 ± 0.11
Support	48.9 ± 11.0	34.4 ± 6.1	0.72 ± 0.12
Other	53.3 ± 11.6	33.9 ± 5.3	0.65 ± 0.13

***Male collegiate swimmers (Oyama, 2006).**

Compared to the normative threshold, 14.3-50.0% of USASOC personnel demonstrated suboptimal performance for shoulder internal rotation strength, 21.4-66.7% for shoulder external rotation strength, and 33.3-71.4% for external rotation/internal rotation strength ratio. Bilateral asymmetry was identified in 53.8% of USASOC personnel for internal rotation strength and 39.6% for external rotation strength.

Shoulder Protraction, Retraction and Elevation Strength

Testing Methodology:

Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)

5 repetitions

Average peak torque/BW

Purpose: Examine scapular stabilizer strength

Background: Scapular stabilization strength is critical for the performance of demanding upper limb tasks. Scapular protractor, retractor, and elevation muscle performance is critical for shielding the shoulder complex from potentially injurious forces. The shoulder complex is dependent on the health of the scapular stabilizers as sources of dynamic joint stabilization. Deficiencies in strength or reciprocal balance of the scapular stabilizer musculature will predispose the shoulder complex to altered kinematics, leading to acute and/or chronic shoulder joint instability, shoulder impingement syndromes, rotator cuff tears, trapped nerves, and occluded blood supply throughout the arm. Further, shoulder protractor-retractor and elevation strength testing consistently detects persistent and potentially dangerous muscle weakness after previous upper limb injury.

Data and Results:

RIGHT

	Protraction (% BW)	Retraction (% BW)	Pro/Ret (Ratio)	Upper Trapezius (% BW)
Top 10th %tile 3SFG	612.3	646.7	--	713.1
Top 25th %tile 3SFG	558.4	585.5	--	653.7
50th %tile 3SFG	461.2	479.8	--	574.5
Bottom 25th %tile 3SFG	395.6	377.1	--	486.5
Athlete*	494.0 ± 96.0	469.0 ± 80.0	1.18 ± 0.23	--
USASOC (All)	442.3 ± 109.8	449.7 ± 126.6	1.01 ± 0.22	547.3 ± 108.0
18 Series (3/5 SFG)	470.9 ± 110.2	476.0 ± 130.3	1.02 ± 0.23	566.1 ± 115.3
SWCS (18 Series)	426.9 ± 83.3	459.8 ± 115.9	0.97 ± 0.24	558.0 ± 80.5
Q-Course	427.4 ± 92.9	434.5 ± 112.2	1.03 ± 0.27	518.5 ± 88.0
Support	408.5 ± 80.7	421.0 ± 89.3	0.98 ± 0.15	515.6 ± 99.9
Other	382.9 ± 125.7	378.3 ± 134.6	1.04 ± 0.23	514.5 ± 94.2

LEFT

	Protraction (% BW)	Retraction (% BW)	Pro/Ret (Ratio)	Upper Trapezius (% BW)
Top 10th %tile 3SFG	591.9	680.8	--	693.3
Top 25th %tile 3SFG	528.3	604.2	--	632.5
50th %tile 3SFG	441.3	509.1	--	572.4
Bottom 25th %tile 3SFG	354.6	419.7	--	484.1
Athlete*	494.0 ± 96.0	469.0 ± 80.0	1.18 ± 0.23	--
USASOC (All)	404.7 ± 108.1	467.6 ± 140.2	0.90 ± 0.26	537.7 ± 104.8
18 Series (3/5 SFG)	440.7 ± 112.9	502.2 ± 143.0	0.92 ± 0.29	559.3 ± 106.3
SWCS (18 Series)	354.8 ± 81.4	429.4 ± 144.3	0.90 ± 0.34	541.1 ± 81.6
Q-Course	366.1 ± 131.0	426.8 ± 147.8	0.88 ± 0.24	521.4 ± 90.1
Support	355.6 ± 73.8	421.5 ± 97.1	0.85 ± 0.12	517.0 ± 102.8
Other	362.5 ± 76.9	421.4 ± 140.7	0.91 ± 0.18	479.6 ± 96.4

***Protraction and Retraction: Healthy overhead athletes (Cools, 2005). Protraction/Retraction Ratio: Top 10th Percentile of SBT-22.**

Compared to the normative threshold, 43.3-87.5% of USASOC personnel demonstrated suboptimal performance for shoulder protraction strength, 35.7-62.5% for shoulder retraction strength, and 66.0-96.7% for protraction/retraction strength ratio. Bilateral asymmetry was identified in 56.7-87.5% of USASOC personnel for protraction strength and 37.5-70.8% for retraction strength.

Torso Flexion and Extension Strength

Testing Methodology:

Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)

5 repetitions

Average peak torque/BW

Purpose: Examine flexion and extension torso strength

Background: Adequate torso muscle strength is important for the safe, efficient, and effective performance of virtually all demanding upper limb, lower limb, and whole-body tasks. Spinal muscle performance is critical for shielding the lower back's anatomical structures and connective tissues from potentially injurious forces. The lower back bones, discs, joints, nerves, and blood vessels are dependent on the health of the torso muscles as sources of dynamic joint stabilization and tissue stress-shields. Deficiencies in strength or reciprocal balance of the torso musculature may lead to injury to the lower back. Moreover, torso strength testing may reveal persistent torso muscle weakness after traumatic and overuse lower back injury which could lead to future injury.

Data and Results:

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 3SFG	232.3	423.0	--
Top 25th %tile 3SFG	214.8	355.7	--
50th %tile 3SFG	194.0	297.9	--
Bottom 25th %tile 3SFG	169.3	260.4	--
Athlete*	280.0 ± 40.0	650.0 ± 120.0	--
Triathletes	238.9 ± 40.9	415.0 ± 96.7	1.75 ± 0.34
USASOC (All)	190.1 ± 33.1	291.0 ± 73.5	1.54 ± 0.35
18 Series (3/5 SFG)	192.8 ± 35.0	310.8 ± 78.4	1.63 ± 0.38
SWCS (18 Series)	185.8 ± 29.3	293.1 ± 41.9	1.61 ± 0.34
Q-Course	203.7 ± 43.6	310.9 ± 86.0	1.53 ± 0.23
Pre Q-Course	190.6 ± 29.4	270.1 ± 66.4	1.42 ± 0.31
Support	189.7 ± 31.7	270.9 ± 75.3	1.43 ± 0.33
Other	180.3 ± 31.0	268.8 ± 58.5	1.5 ± 0.26

***Flexion and Extension: Collegiate male wrestlers (Iwai, 2008). Extension/Flexion Ratio: Healthy adults (Smith, 1985).**

Compared to the normative threshold, 66.7-97.1% of USASOC personnel demonstrated suboptimal performance for torso flexion strength, 100% for torso extension strength, and 44.4-71.6% for external rotation/internal rotation strength ratio.

Knee Flexion and Extension Strength

Testing Methodology:

Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)

5 repetitions

Average peak torque/BW

Purpose: Examine knee flexion and extension strength

Background: Adequate strength of the hamstring and quadriceps muscle groups is vital for the safe and effective performance of potentially injurious landing tasks and change-of-direction maneuvers associated with tactical operations and physical training. These muscle groups contribute to the dissipation of imposed forces and neuromuscular control of the knee joint during demanding lower extremity activities. Maintenance of appropriate strength ratios between the hamstring and quadriceps muscle groups may minimize the risk factors associated with traumatic and overuse lower extremity injuries during training.

Data and Results:

RIGHT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 3SFG	163.7	298.6	--
Top 25th %tile 3SFG	143.7	268.1	--
50th %tile 3SFG	128.4	244.6	--
Bottom 25th %tile 3SFG	115.1	206.6	--
Athlete*	170.0 ± 22.0	270.0 ± 41.0	0.65 ± 0.11
Triathletes	128.0 ± 22.6	242.1 ± 50.4	0.55 ± 0.09
Normative	--	--	0.60 - 0.80
USASOC (All)	124.9 ± 24.3	233.1 ± 44.1	0.54 ± 0.10
18 Series (3/5 SFG)	131.1 ± 23.3	241.2 ± 46.5	0.55 ± 0.11
SWCS (18 Series)	124.0 ± 17.2	223.9 ± 39.7	0.57 ± 0.11
Q-Course	128.0 ± 10.7	249.5 ± 21.1	0.51 ± 0.03
Pre Q-Course	120.7 ± 23.5	241.7 ± 41.6	0.50 ± 0.07
Support	115.9 ± 23.3	219.1 ± 45.7	0.54 ± 0.10
Other	121.1 ± 30.5	217.5 ± 37.8	0.55 ± 0.09

LEFT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 3SFG	160.8	289.0	--
Top 25th %tile 3SFG	142.1	262.1	--
50th %tile 3SFG	125.0	224.7	--
Bottom 25th %tile 3SFG	110.7	204.2	--
Athlete*	170.0 ± 22.0	270.0 ± 41.0	0.65 ± 0.11
Triathletes	128.5 ± 23.2	241.3 ± 42.9	0.53 ± 0.06
Normative	--	--	0.60 - 0.80
USASOC (All)	120.7 ± 23.8	225.3 ± 41.9	0.54 ± 0.08
18 Series (3/5 SFG)	127.5 ± 24.7	231.8 ± 42.9	0.55 ± 0.08
SWCS (18 Series)	123.3 ± 16.9	224.6 ± 32.4	0.56 ± 0.07
Q-Course	124.2 ± 13.4	234.2 ± 16.2	0.53 ± 0.09
Pre Q-Course	118.0 ± 25.9	231.9 ± 42.9	0.51 ± 0.08
Support	113.1 ± 22.1	210.1 ± 43.9	0.54 ± 0.09
Other	110.6 ± 20.6	214.7 ± 40.9	0.52 ± 0.06

***Rugby union players (Newman, 2004).**

Compared to the normative threshold, 77.5-100% of USASOC personnel demonstrated suboptimal performance for knee flexion strength, 44.4-83.3% for knee extension strength, and 46.0-88.9% for knee flexion/extension strength ratio. Bilateral asymmetry was identified in 28.6-55.6% of USASOC personnel for knee flexion strength and 33.3-50.0% for knee extension strength.

Musculoskeletal Flexibility Shoulder Flexion and Extension

Testing Methodology:

Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)

3 measures

Passive shoulder flexion and extension

Average of 3 joint angles (°)

Purpose: Examine shoulder flexion and extension flexibility

Background: Shoulder range of motion (ROM) is critical for maintenance of proper glenohumeral and shoulder girdle kinematics. A deficit in shoulder ROM will significantly impact overall performance during demanding overhead and upper extremity tasks and predispose the Operator to potentially traumatic and/or chronic pathologies.

Data and Results:

RIGHT

	Flexion (degrees)	Extension (degrees)
Top 10th %tile 3SFG	190.0	81.5
Top 25th %tile 3SFG	185.0	74.4
50th %tile 3SFG	181.3	68.9
Bottom 25th %tile 3SFG	179.6	60.0
Athlete*	168.0 ± 8.7	81.0 ± 11.8
Triathletes	177.4 ± 10.9	69.2 ± 8.5
Clinical Range	170.0-190.0	50.0-70.0
USASOC (All)	182.1 ± 7.9	68.6 ± 11.6
18 Series (3/5 SFG)	182.1 ± 7.5	67.5 ± 11.7
SWCS (18 Series)	181.6 ± 5.9	71.3 ± 8.1
Q-Course	184.0 ± 5.2	71.2 ± 6.6
Support	181.8 ± 10.8	71.6 ± 13.6
Other	181.8 ± 7.9	67.9 ± 11.3

LEFT

	Flexion (degrees)	Extension (degrees)
Top 10th %tile 3SFG	190.2	80.7
Top 25th %tile 3SFG	185.0	73.1
50th %tile 3SFG	180.7	65.5
Bottom 25th %tile 3SFG	178.5	60.0
Athlete*	168.0 ± 8.7	81.0 ± 11.8
Triathletes	176.7 ± 10.7	71.4 ± 9.2
Clinical Range	170.0-190.0	50.0-70.0
USASOC (All)	181.3 ± 8.9	68.1 ± 11.3
18 Series (3/5 SFG)	181.5 ± 8.6	66.4 ± 11.5
SWCS (18 Series)	181.7 ± 7.6	70.5 ± 7.8
Q-Course	185.5 ± 4.6	74.3 ± 8.2
Support	180.1 ± 9.6	71.8 ± 11.8
Other	180.6 ± 10.4	67.4 ± 11.2

***Non-dominant arm of professional baseball position players (Brown, 1988).**

Compared to the clinical range, up to 10.0% of USASOC personnel demonstrated suboptimal motion for shoulder flexion and 9.4% for shoulder extension.

Shoulder External and Internal Rotation and Posterior Shoulder Tightness Flexibility

Testing Methodology:

Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)

3 measures

Passive shoulder external rotation, internal rotation, and posterior shoulder tightness

Average of 3 joint angles (°)

Purpose: Examine shoulder external (ER) and internal rotation (IR) and Posterior Shoulder Tightness (PST) flexibility

Background: A balance between ER and IR flexibility is desired to maintain appropriate glenohumeral joint kinematics and contributes to better physical performance during overhead activities. Posterior shoulder tightness (PST) may be the result of inflexible rotator cuff muscles and/or tightening of the posterior joint capsule which may lead to glenohumeral joint dysfunction and impingement syndromes.

Data and Results:

RIGHT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 3SFG	119.4	90.0	123.7
Top 25th %tile 3SFG	105.7	66.0	117.0
50th %tile 3SFG	98.7	60.0	109.7
Bottom 25th %tile 3SFG	92.0	50.0	102.3
Athlete*	124.0 ± 12.7	91.0 ± 13.0	105.0 ± 11.4
Triathletes	111.8 ± 7.1	54.3 ± 9.1	109.7 ± 7.0
Clinical Range	90.0-110.0	50.0-65.0	100.0-120.0
USASOC (All)	105.2 ± 26.6	61.3 ± 15.7	107.1 ± 15.9
18 Series (3/5 SFG)	107.0 ± 30.9	61.7 ± 18.2	106.1 ± 18.6
SWCS (18 Series)	96.6 ± 9.1	56.2 ± 8.2	110.5 ± 6.9
Q-Course	97.8 ± 13.3	54.5 ± 11.4	107.1 ± 5.3
Pre Q-Course	105.1 ± 11.1	61.1 ± 7.8	111.4 ± 10.2
Support	99.6 ± 7.4	59.6 ± 11.2	109.7 ± 8.5
Other	111.8 ± 39.6	66.2 ± 19.5	101.8 ± 20.5

LEFT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 3SFG	120.8	83.6	124.0
Top 25th %tile 3SFG	104.3	68.3	118.0
50th %tile 3SFG	95.3	61.5	110.0
Bottom 25th %tile 3SFG	90.0	55.0	104.3
Athlete*	124.0 ± 12.7	91.0 ± 13.0	105.0 ± 11.4
Triathletes	109.1 ± 8.6	62.4 ± 9.7	110.9 ± 7.6
Clinical Range	90.0-110.0	50.0-65.0	100.0-120.0
USASOC (All)	102.8 ± 27.8	64.9 ± 14.0	107.6 ± 16.5
18 Series (3/5 SFG)	104.2 ± 31.9	64.2 ± 15.6	107.1 ± 18.3
SWCS (18 Series)	93.4 ± 12.7	64.0 ± 10.2	111.5 ± 6.8
Q-Course	100.7 ± 10.9	61.6 ± 15.5	109.1 ± 6.5
Pre Q-Course	100.6 ± 12.9	65.8 ± 8.8	109.6 ± 14.8
Support	97.8 ± 9.9	63.9 ± 10.1	109.5 ± 7.0
Other	110.8 ± 40.8	68.5 ± 17.2	102.8 ± 22.8

***Internal and External Rotation: Non-dominant arm of professional baseball position players (Brown, 1988). Posterior Shoulder Tightness: Male collegiate swimmers (Oyama, 2006).**

Compared to the clinical range, 8.8-40% of USASOC personnel demonstrated suboptimal motion for shoulder external rotation, 2.9-44.4% for shoulder internal rotation, and 5.4-22.2% for posterior shoulder tightness.

Hip Extension Flexibility

Testing Methodology:

Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)

3 measures

Passive hip extension

Average of 3 joint angles (°)

Purpose: Examine hip extension flexibility

Background: Hip musculature flexibility is essential for the mobility and generation of force necessary to perform all physical tasks involving the lower extremity. Flexibility deficits at the hip will negatively impact overall performance, contributing to altered kinematics and increased stresses on distal joints leading to acute and chronic injuries that threaten the stability of the lower extremity.

Data and Results:

	Right Extension (degrees)	Left Extension (degrees)
Top 10th %tile 3SFG	30.8	30.0
Top 25th %tile 3SFG	26.5	25.9
50th %tile 3SFG	23.0	23.0
Bottom 25th %tile 3SFG	20.0	20.2
Triathletes	21.0 ± 8.5	20.7 ± 6.3
Normative	17.4 ± 5.9	17.4 ± 5.9
Clinical Range	20.0-40.0	20.0-40.0
USASOC (All)	23.0 ± 4.5	23.3 ± 4.4
18 Series (3/5 SFG)	23.7 ± 4.7	23.8 ± 4.5
SWCS (18 Series)	22.3 ± 4.4	22.9 ± 3.2
Q-Course	22.7 ± 2.1	22.7 ± 2.6
Support	22.3 ± 4.1	22.4 ± 4.4
Other	21.6 ± 4.4	23.1 ± 4.9

***Healthy General Population, males 20-44 years old (Soucie, 2011).**

Compared to the clinical range, 7.1-34.5% of USASOC personnel demonstrated suboptimal motion for hip extension.

Knee Hamstring Flexibility

Testing Methodology:

Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)

3 measures

Active knee hamstring

Average of 3 joint angles (°)

Purpose: Examine knee hamstring flexibility

Background: Maintenance of appropriate flexibility between the quadriceps and hamstring muscle groups contributes to maximal force generation across the available range of motion while also providing for the dynamic stabilization and stiffness necessary for joint protection during demanding tasks involving the lower extremity. Deficits in flexibility in one or both of these muscle groups may contribute to acute or chronic injuries affecting the proper functioning of the knee and jeopardizing overall joint stability.

Data and Results:

	Right Active Knee Extension (degrees)	Left Active Knee Extension (degrees)
Top 10th %tile 3SFG	3.5	7.5
Top 25th %tile 3SFG	9.8	13.5
50th %tile 3SFG	19.5	20.0
Bottom 25th %tile 3SFG	28.1	29.3
Athlete*	34.2 ± 11.9	34.2 ± 11.9
Triathletes	14.5 ± 11.4	14.4 ± 9.6
Clinical Range	0-10.0	0-10.0
USASOC (All)	21.5 ± 21.7	23.5 ± 22.1
18 Series (3/5 SFG)	24.8 ± 25.4	26.5 ± 25.5
SWCS (18 Series)	15.4 ± 9.7	19.2 ± 8.9
Q-Course	10.6 ± 9.4	12.1 ± 8.2
Pre Q-Course	17.2 ± 12.2	19.0 ± 12.7
Support	15.8 ± 9.8	16.7 ± 8.7
Other	27.2 ± 28.1	30.8 ± 29.9

Compared to the clinical range, 44.4-85.7% of USASOC personnel demonstrated suboptimal motion for active knee extension.

Calf Flexibility

Testing Methodology:

Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)

3 measures

Active ankle dorsiflexion

Average of 3 joint angles (°)

Purpose: Examine ankle dorsiflexion flexibility

Background: Adequate flexibility of the calf musculature contributes to proper mechanical functioning of the knee and ankle joints as well as the generation of forces necessary for tasks such as running and jumping. Deficits in calf musculature flexibility will have a negative impact on overall physical performance and may contribute to acute and/or chronic injuries involving the knee and ankle.

Data and Results:

	Right Dorsiflexion (degrees)	Left Dorsiflexion (degrees)
Top 10th %tile 3SFG	19.3	20.0
Top 25th %tile 3SFG	17.0	17.3
50th %tile 3SFG	13.3	14.5
Bottom 25th %tile 3SFG	11.0	12.0
Clinical Range	10.0-25.0	10.0-25.0
USASOC (All)	14.1 ± 3.9	14.5 ± 4.0
18 Series (3/5 SFG)	13.7 ± 4.1	14.2 ± 4.4
SWCS (18 Series)	15.2 ± 4.1	16.3 ± 3.6
Q-Course	12.9 ± 2.1	13.6 ± 2.9
Pre Q-Course	13.9 ± 4.9	13.7 ± 4.3
Support	14.9 ± 3.4	15.2 ± 3.3
Other	14.4 ± 3.1	14.7 ± 3.4

Compared to the clinical range, 7.1-35.0% of USASOC personnel demonstrated suboptimal motion for ankle dorsiflexion.

Posture

Testing Methodology:

Modified 40cm combination square (Swanson)

Standing forward shoulder posture and supine pectoralis minor length

Average of 3 measurements (cm)

Purpose: Examine shoulder girdle posture and pectoralis minor length

Background: Proper shoulder-neck-head postural alignment is important for the performance of rapid, coordinated head-on-neck and all upper limb movements. Appropriate postural alignment is critical for ensuring loads are evenly distributed over the upper body's joint surfaces and within the upper body's variety of tissues. Abnormal postural alignment may result in stress focus points within the joints and/or tissues which could lead to overuse injury or pain and may cause nerves and blood vessels to become trapped as they run from the neck down the arm.

Data and Results:

FORWARD SHOULDER

	Right Forward Shoulder (cm)	Left Forward Shoulder (cm)
Top 10th %tile 3SFG	14.0	14.1
Top 25th %tile 3SFG	15.2	15.2
50th %tile 3SFG	16.3	16.4
Bottom 25th %tile 3SFG	17.8	17.8
Athlete*	14.5 ± 2.1	14.5 ± 2.1
USASOC (All)	16.4 ± 1.9	16.5 ± 1.9
18 Series (3/5 SFG)	16.4 ± 1.9	16.5 ± 1.9
SWCS (18 Series)	16.2 ± 2.2	16.4 ± 1.9
Q-Course	15.9 ± 1.5	15.9 ± 1.7
Support	16.0 ± 1.8	16.1 ± 1.6
Other	17.1 ± 1.9	17.1 ± 2.1

***Forward Shoulder: Male collegiate swimmers, dominant=right and non-dominant=left (Oyama, 2006).**

Compared to the clinical range, 12.5-66.7% of USASOC personnel demonstrated suboptimal alignment for forward shoulder posture.

PECTORALIS MINOR

	Right Pectoralis Minor (cm)	Left Pectoralis Minor (cm)
Top 10th %tile 3SFG	5.5	5.6
Top 25th %tile 3SFG	6.4	6.8
50th %tile 3SFG	7.6	7.6
Bottom 25th %tile 3SFG	8.3	8.3
Normative	6.3 ± 1.4	6.3 ± 1.4
USASOC (All)	7.6 ± 1.1	7.7 ± 1.1
18 Series (3/5 SFG)	7.4 ± 1.2	7.5 ± 1.2
SWCS (18 Series)	7.9 ± 0.7	8.1 ± 0.8
Q-Course	7.5 ± 1.2	7.3 ± 1.3
Support	7.8 ± 0.7	8.0 ± 0.8
Other	7.9 ± 1.1	8.1 ± 1.1

***Pectoralis Minor: Healthy General Population, dominant=right and non-dominant=left (Lewis, 2007).**

Compared to the normative threshold, 72.9-100.0-% of USASOC personnel demonstrated insufficient pectoralis minor length.

Balance Dynamic Postural Stability

Testing Methodology:

Kistler force plate
Average of 3 trials

Purpose: Examine dynamic postural stability through single-leg jump landing

Background: The dynamic postural stability index (DPSI) was used to quantify dynamic postural stability. The DPSI provides stability indices for the medial-lateral (MLSI), anterior-posterior (APSI), and vertical (VSI) direction as well as a composite score (DPSI). Lower scores indicate better dynamic postural stability. Accurate sensory information, as measured through single-leg jump landing testing, is essential to the performance of complex motor patterns, maintaining dynamic joint stability, and preventing injury. Deficits in this area may indicate a greater risk for knee, ankle, and lower limb injury.

RIGHT

	MLSI	APSI	VSI	DPSI
Top 10th %tile 3SFG	0.0231	0.1178	0.2757	0.3087
Top 25th %tile 3SFG	0.0268	0.1242	0.3087	0.3391
50th %tile 3SFG	0.0310	0.1323	0.3381	0.3662
Bottom 25th %tile 3SFG	0.0339	0.1414	0.3589	0.3850
Athlete*	0.0300	0.1400	0.3939	0.3500
USASOC (All)	0.0320 ± 0.0066	0.1306 ± 0.0112	0.3324 ± 0.0403	0.3633 ± 0.0392
18 Series (3/5 SFG)	0.0307 ± 0.0058	0.1326 ± 0.0117	0.3349 ± 0.0425	0.3636 ± 0.0420
SWCS (18 Series)	0.0309 ± 0.0045	0.1285 ± 0.0105	0.3185 ± 0.0377	0.3522 ± 0.0447
Q-Course	0.0325 ± 0.0059	0.1308 ± 0.0081	0.3390 ± 0.0230	0.3600 ± 0.0037
Pre Q-Course	0.0334 ± 0.0073	0.1307 ± 0.0102	0.3356 ± 0.0338	0.3621 ± 0.0330
Support	0.0343 ± 0.0068	0.1273 ± 0.0128	0.3274 ± 0.0469	0.3723 ± 0.0430
Other	0.0331 ± 0.0081	0.1289 ± 0.0090	0.3327 ± 0.0372	0.3612 ± 0.0411

LEFT

	MLSI	APSI	VSI	DPSI
Top 10th %tile 3SFG	0.0223	0.1191	0.2717	0.2995
Top 25th %tile 3SFG	0.0241	0.1240	0.2992	0.3277
50th %tile 3SFG	0.0281	0.1326	0.3283	0.3531
Bottom 25th %tile 3SFG	0.0322	0.1380	0.3524	0.3790
USASOC (All)	0.0297 ± 0.0062	0.1294 ± 0.0109	0.3274 ± 0.0391	0.3538 ± 0.0374
18 Series (3/5 SFG)	0.0286 ± 0.0058	0.1315 ± 0.0096	0.3266 ± 0.0429	0.3538 ± 0.0406
SWCS (18 Series)	0.0298 ± 0.0062	0.1272 ± 0.0133	0.3121 ± 0.0328	0.3389 ± 0.0302
Q-Course	0.0303 ± 0.0054	0.1308 ± 0.0085	0.3434 ± 0.0221	0.3690 ± 0.0208
Pre Q-Course	0.0319 ± 0.0085	0.1307 ± 0.0094	0.3364 ± 0.0299	0.3628 ± 0.0281
Support	0.0298 ± 0.0056	0.1266 ± 0.0128	0.3277 ± 0.0429	0.3529 ± 0.0428
Other	0.0305 ± 0.0047	0.1254 ± 0.0117	0.3241 ± 0.0364	0.3493 ± 0.0353

***Recreational active males (Pederson, 2011).**

Compared to the normative threshold, 23.1-35.5% of USASOC personnel demonstrated suboptimal performance for medial/lateral postural stability, 1.1-2.7% for anterior/posterior postural stability, 17.6-20.5% for vertical postural stability, and 19.2-22.6% dynamic postural stability. Bilateral asymmetry for postural stability was identified in 56.0% of USASOC personnel for medial/lateral, 9.9% for anterior/posterior, 26.9% for vertical, and 18.7% for dynamic.

Biomechanics

Scapular Kinematics: Humeral Elevation and Depression in the Scapular Plane

Testing Methodology:

3D optical capture system (Vicon, Centennial, CO)

Purpose: Examine scapular kinematics with respect to the thorax

Background: Abnormal scapular kinematics, such as decreased scapular lateral rotation, is theorized to be related to shoulder injuries and pathologies such as subacromial impingement, as well as decreased athletic performance. Such altered scapular kinematics has been identified in athletes involved in overhead throwing or rock climbing, as well as patients with shoulder impingement injury. Overhead tasks such as reaching, loading of boats, climbing, and swimming are commonly performed by an Operator in military training and missions, and normal scapular kinematics are a critical component for Operators to perform such tasks while minimizing the risk of injury.

Data and Results:

RIGHT HUMERAL ELEVATION

	90 Degrees			120 Degrees		
	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)
Top 10th %tile 3SFG	20.6	34.6	-1.4	20.0	44.2	6.3
Top 25th %tile 3SFG	24.2	30.3	-4.7	24.7	39.2	2.1
50th %tile 3SFG	30.0	25.4	-9.2	33.0	34.2	-3.0
Bottom 25th %tile 3SFG	34.6	19.3	-12.5	41.3	27.2	-7.2
Normative*	36.8 ± 10.9	18.0 ± 9.4	-4.2 ± 6.3	39.0 ± 12.8	24.9 ± 9.4	3.2 ± 9.7
Athlete*	43.5	--	-9.9	47.5	40.7	-8.1
USASOC (All)	29.8 ± 6.7	26.6 ± 6.3	-8.9 ± 5.4	32.3 ± 9.3	35.1 ± 7.1	-2.8 ± 6.6
18 Series (3/5 SFG)	30.1 ± 7.0	25.3 ± 6.9	-8.7 ± 5.5	33.1 ± 9.7	33.5 ± 7.7	-2.6 ± 6.4
SWCS (18 Series)	26.8 ± 6.5	28.1 ± 6.2	-8.0 ± 3.9	27.3 ± 9.3	36.0 ± 5.6	-0.1 ± 5.9
Q-Course	28.1 ± 5.8	25.0 ± 5.0	-8.5 ± 4.5	29.4 ± 7.8	33.1 ± 5.9	-1.4 ± 5.4
Support	29.8 ± 6.4	29.4 ± 4.7	-9.0 ± 5.1	32.0 ± 8.8	38.8 ± 5.8	-3.9 ± 6.3
Other	31.8 ± 6.5	27.8 ± 5.0	-10.1 ± 6.6	34.9 ± 8.5	36.6 ± 5.6	-4.6 ± 8.0

LEFT HUMERAL ELEVATION

	90 Degrees			120 Degrees		
	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)
Top 10th %tile 3SFG	22.0	33.3	0.6	20.0	40.9	6.5
Top 25th %tile 3SFG	25.6	29.5	-3.2	24.9	37.4	3.2
50th %tile 3SFG	30.5	25.0	-8.0	30.8	32.5	-1.6
Bottom 25th %tile 3SFG	34.8	19.4	-11.8	36.1	27.7	-5.4
Normative*	36.8 ± 10.9	18.0 ± 9.4	-4.2 ± 6.3	39.0 ± 12.8	24.9 ± 9.4	3.2 ± 9.7
Athlete*	43.5	--	-9.9	47.5	40.7	-8.1
USASOC (All)	30.3 ± 6.5	25.6 ± 5.7	-7.9 ± 5.4	30.8 ± 8.4	34.0 ± 6.4	-1.4 ± 6.2
18 Series (3/5 SFG)	30.1 ± 6.0	24.5 ± 6.2	-7.5 ± 5.7	31.2 ± 8.6	32.7 ± 6.9	-1.5 ± 6.3
SWCS (18 Series)	29.7 ± 6.6	26.6 ± 3.7	-7.3 ± 3.0	29.3 ± 6.8	35.2 ± 5.3	1.0 ± 3.9
Q-Course	30.5 ± 7.0	24.8 ± 4.6	-10.0 ± 4.7	28.8 ± 8.0	33.1 ± 5.5	-1.1 ± 5.8
Support	30.4 ± 7.4	28.0 ± 5.5	-7.5 ± 4.7	29.6 ± 7.9	36.5 ± 6.1	-0.5 ± 5.7
Other	31.6 ± 7.5	26.3 ± 4.3	-9.1 ± 6.7	32.6 ± 9.4	35.0 ± 4.8	-3.7 ± 7.8

RIGHT HUMERAL DEPRESSION

	90 Degrees			120 Degrees		
	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)
Top 10th %tile 3SFG	18.9	34.9	0.4	18.9	45.4	7.3
Top 25th %tile 3SFG	23.3	30.9	-3.3	25.2	38.4	3.5
50th %tile 3SFG	30.5	26.7	-6.9	34.5	34.8	-1.3
Bottom 25th %tile 3SFG	35.6	20.4	-11.2	42.5	27.0	-5.4
Normative*	36.8 ± 10.9	18.0 ± 9.4	-4.2 ± 6.3	39.0 ± 12.8	24.9 ± 9.4	3.2 ± 9.7
Athlete*	44.0	-	-7.3	46.0	-39.2	-5.3
USASOC(All)	29.1 ± 7.1	27.3 ± 6.6	-7.1 ± 5.9	32.5 ± 9.9	35.1 ± 7.3	-1.5 ± 6.8
18 Series (3/5 SFG)	29.4 ± 7.4	26.1 ± 6.8	-6.9 ± 5.8	33.5 ± 10.4	33.5 ± 7.8	-1.2 ± 6.3
SWCS (18 Series)	25.8 ± 7.2	29.0 ± 5.7	-5.9 ± 4.5	26.8 ± 8.2	36.7 ± 5.7	1.5 ± 5.2
Q-Course	28.4 ± 7.1	25.4 ± 6.3	-6.8 ± 6.7	30.7 ± 8.9	33.1 ± 6.1	-0.5 ± 7.4
Support	29.0 ± 6.6	30.1 ± 5.8	-7.5 ± 5.8	31.9 ± 9.4	38.6 ± 6.3	-2.6 ± 7.1
Other	30.9 ± 6.6	27.8 ± 6.7	-8.6 ± 7.5	34.1 ± 9.5	36.9 ± 5.8	-3.5 ± 9.0

LEFT HUMERAL DEPRESSION

	90 Degrees			120 Degrees		
	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)	IR(+)/ER (-)	UR (+)/DR (-)	AT(-)/PT (+)
Top 10th %tile 3SFG	20.7	33.1	2.9	18.3	42.0	7.7
Top 25th %tile 3SFG	23.7	29.7	-1.4	25.1	37.2	4.2
50th %tile 3SFG	28.2	25.4	-6.5	30.5	33.2	-0.3
Bottom 25th %tile 3SFG	33.2	20.3	-10.3	35.7	27.0	-4.1
Normative*	36.8 ± 10.9	18.0 ± 9.4	-4.2 ± 6.3	39.0 ± 12.8	24.9 ± 9.4	3.2 ± 9.7
Athlete*	44.0	-	-7.3	46.0	-39.2	-5.3
USASOC(All)	28.9 ± 6.6	26.4 ± 5.6	-6.2 ± 5.7	30.4 ± 8.6	34.1 ± 6.5	-0.1 ± 6.3
18 Series (3/5 SFG)	28.4 ± 6.1	25.3 ± 5.9	-5.8 ± 5.9	30.8 ± 8.9	32.8 ± 6.9	-0.3 ± 6.3
SWCS (18 Series)	28.9 ± 7.5	27.4 ± 4.1	-5.8 ± 3.1	28.8 ± 7.4	35.6 ± 5.0	1.9 ± 4.0
Q-Course	29.2 ± 7.3	25.6 ± 5.6	-8.1 ± 4.8	28.6 ± 7.5	33.3 ± 6.4	0.9 ± 7.0
Support	29.1 ± 7.0	28.7 ± 5.0	-5.5 ± 5.1	29.3 ± 8.3	36.4 ± 6.3	0.7 ± 5.5
Other	30.1 ± 7.5	27.2 ± 5.3	-7.8 ± 6.9	32.2 ± 9.4	35.6 ± 5.2	-2.7 ± 7.5

***Right Elevation & Depression: Male construction workers (Borstad, 2002). Normative Population: Healthy & physically active males (Myers, 2005)**

Because the scapula serves as the foundation for shoulder motion adequate and optimal motion is necessary for overhead tasks to allow for proper alignment of the upper arm which prevents impingement and shoulder injury. In order to maintain optimal alignment during overhead activity it is necessary for the scapula to upwardly rotate, tilt posteriorly and externally rotate. This allows the upper arm to move smoothly and decreases the risk of overuse injuries.

Normal scapular internal rotation is approximately 35-40° during humeral elevation/depression above 90°; increased internal rotation may contribute to potential shoulder injury. The average scapular internal rotation at 90° humeral elevation for 3-5SFG Operators was comparable to all Operator groups (18 Series, SWCS, Q-Course, Support and Other), but was less than both the normative and an athlete groups by up to 9° and 16° respectively. The average scapular internal rotation at 120° humeral elevation for 3-5SFG Operators was comparable to Support and Other groups, up to 6° greater than SWCS, and 5°

greater than Q-Course, but was less than both the normative and an athlete groups by up to 9° and 17° respectively. On average the 3SFG Operators demonstrated favorable scapular internal rotation during overhead humeral elevation.

Normal scapular upward rotation is approximately 18-40° during humeral elevation/depression above 90°; decreased upward rotation may contribute to potential shoulder injury. The average scapular upward rotation at 90° humeral elevation for 3SFG Operators demonstrated less upward rotation compared to all Operator groups by up to 5°, but was 7° greater than the normative group. The average scapular upward rotation at 120° humeral elevation for 3SFG Operators demonstrated less upward rotation compared to all Operator groups by up to 5°, but was up to 9° greater than the normative group and up to 9° less than the athlete group. On average the 3SFG Operators demonstrated favorable scapular upward rotation during overhead humeral elevation.

Normal scapular anterior tilt is approximately -4-3° (anterior tilt is negative) during humeral elevation/depression and moves toward/into posterior tilt as the arm approaches 120° of elevation; increased anterior tilt may contribute to potential shoulder injury. The average scapular anterior tilt at 90° humeral elevation for 3SFG Operators was comparable to all Operators and the athlete group, but was up to 4° more anteriorly tilted compared to the normative population. The average scapular anterior tilt at 120° humeral elevation for 3SFG Operators was comparable to all Operators, but was up to 5° more anteriorly tilted compared to the normative group and up to 7° less anteriorly tilted compared to the athlete group. On average the 3SFG operators demonstrated favorable scapular anterior tilt during humeral elevation.

Biomechanics
Hip Kinematics: Two-Legged Stop-Jump

Testing Methodology:

3D optical capture system (Vicon, Centennial, CO)

Purpose:

Examine hip flexion at initial contact

Background:

The hip and surrounding musculature play an essential role in lower extremity dynamic stability. Landing with greater flexion at the hip will allow for more efficient use of the strong muscles of the hip and subsequent absorption of joint forces.

Data and Results:

RIGHT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 3SFG	56.9	5 to -5
Top 25th %tile 3SFG	50.1	10 to -10
50th %tile 3SFG	42.4	15 to -15
Bottom 25th %tile 3SFG	36.9	20 to -20
Clinical Value	--	0.0
Triathletes	51.1 ± 13.2	-2.6 ± 3.5
USASOC (All)	42.4 ± 9.5	-3.4 ± 3.4
18 Series (3/5 SFG)	43.5 ± 9.6	-4.0 ± 3.5
SWCS (18 Series)	38.6 ± 6.8	-2.2 ± 2.9
Q-Course	47.2 ± 7.7	-3.6 ± 2.0
Support	42.1 ± 11.1	-2.7 ± 4.1
Other	39.0 ± 7.9	-2.9 ± 2.7

LEFT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 3SFG	55.2	5 to -5
Top 25th %tile 3SFG	50.2	10 to -10
50th %tile 3SFG	43.8	15 to -15
Bottom 25th %tile 3SFG	36.7	20 to -20
Clinical Value	--	0.0
Triathletes	54.4 ± 15.4	-2.0 ± 4.2
USASOC (All)	43.2 ± 9.8	-4.3 ± 3.7
18 Series (3/5 SFG)	44.0 ± 9.5	-4.3 ± 3.5
SWCS (18 Series)	40.3 ± 7.3	-4.7 ± 3.3
Q-Course	47.1 ± 8.1	-6.3 ± 4.5
Support	43.0 ± 12.3	-3.4 ± 4.4
Other	40.7 ± 8.9	-4.5 ± 3.1

The hip flexion position at initial contact was inefficient in 70-74% of personnel. Asymmetry was identified in 25% of personnel. Hip abduction angles at initial contact were within the optimal range of +/- 5 degrees, however 30-42% landed in a suboptimal position. Landing asymmetry was identified in 97% of personnel.

Knee Kinematics: Two-Legged Stop-Jump

Testing Methodology:

3D optical capture system (Vicon, Centennial, CO)

Purpose:

Examine maximum knee flexion and knee flexion at initial contact.

Background:

Flexing the knee at landing and throughout dynamic tasks is essential to absorbing the dangerous landing forces experienced throughout the lower extremity. Inadequate flexion combined with a valgus knee angle can increase the strain on knee ligaments which can lead to tissue failure and injury.

Data and Results:

RIGHT

	Knee Flexion @ Initial Contact (degrees)	Knee Valgus @ Initial Contact (degrees)	Maximum Knee Flexion (degrees)
Top 10th %tile 3SFG	37.1	5 to -5	110.0
Top 25th %tile 3SFG	30.4	10 to -10	99.8
50th %tile 3SFG	25.2	15 to -15	89.5
Bottom 25th %tile 3SFG	20.6	20 to -20	83.0
Clinical Value	--	0.0	--
Triathletes	29.9 ± 8.7	5.6 ± 3.8	82.4 ± 11.9
USASOC (All)	24.9 ± 7.5	4.9 ± 5.2	92.3 ± 14.9
18 Series (3/5 SFG)	25.8 ± 7.7	5.2 ± 5.3	92.2 ± 15.1
SWCS (18 Series)	23.0 ± 6.9	2.8 ± 5.5	96.1 ± 17.5
Q-Course	26.4 ± 6.4	6.6 ± 4.7	89.2 ± 19.1
Support	23.9 ± 6.9	5.1 ± 4.4	91.1 ± 15.5
Other	23.2 ± 7.9	4.1 ± 5.4	93.0 ± 10.7

LEFT

	Knee Flexion @ Initial Contact (degrees)	Knee Valgus @ Initial Contact (degrees)	Maximum Knee Flexion (degrees)
Top 10th %tile 3SFG	36.6	5 to -5	113.2
Top 25th %tile 3SFG	30.5	10 to -10	99.7
50th %tile 3SFG	25.2	15 to -15	87.7
Bottom 25th %tile 3SFG	20.2	20 to -20	79.7
Clinical Value	--	0.0	--
Triathletes	34.8 ± 9.5	6.2 ± 9.1	84.8 ± 8.3
USASOC (All)	25.3 ± 7.7	5.4 ± 6.4	90.5 ± 15.6
18 Series (3/5 SFG)	25.6 ± 8.4	5.2 ± 6.4	90.0 ± 15.4
SWCS (18 Series)	24.0 ± 6.3	3.4 ± 5.2	95.0 ± 20.1
Q-Course	26.8 ± 5.9	6.3 ± 5.1	88.5 ± 17.7
Support	24.9 ± 6.9	4.9 ± 6.4	89.9 ± 17.4
Other	24.7 ± 7.3	7.1 ± 7.3	91.6 ± 11.1

The knee flexion angle at initial contact was insufficient in 60.9-84.5%. Knee flexion asymmetry was identified in 68.4%. The knee valgus angle at initial contact was outside of the optimal range (0 +/- 5 degrees) with 53.5-54.6% suboptimal. Knee valgus asymmetry was identified in 92%. Maximum knee flexion was suboptimal in 10.3-15.5% with asymmetry identified in 12% of personnel.

Ground Reaction Forces: Two-Legged Stop-Jump

Testing Methodology:

Kistler force plates (Kistler Corp, Worthington, OH)
Collected at 1200 Hz

Purpose:

Examine peak vertical ground reaction forces

Background:

Vertical ground reaction forces directly correlate with high joint forces. Individuals who are able to decrease landing forces through modified landing strategies should be able to mitigate these forces and reduce their risk of injury.

Data and Results:

RIGHT

	Peak Vertical GRF (%BW)
Top 10th %tile 3SFG	142.6
Top 25th %tile 3SFG	166.6
50th %tile 3SFG	195.5
Bottom 25th %tile 3SFG	240.5
Triathletes	210.8 ± 48.1
USASOC (All)	209.8 ± 70.7
18 Series (3/5 SFG)	212.0 ± 72.1
SWCS (18 Series)	194.5 ± 61.8
Q-Course	238.2 ± 84.6
Support	195.8 ± 54.7
Other	214.6 ± 80.2

LEFT

	Peak Vertical GRF (%BW)
Top 10th %tile 3SFG	145.4
Top 25th %tile 3SFG	165.0
50th %tile 3SFG	189.4
Bottom 25th %tile 3SFG	225.0
Triathletes	224.3 ± 63.2
USASOC (All)	194.7 ± 53.8
18 Series (3/5 SFG)	200.1 ± 53.0
SWCS (18 Series)	189.1 ± 61.8
Q-Course	200.8 ± 67.4
Support	180.9 ± 45.6
Other	187.6 ± 56.5

Peak ground reaction forces were suboptimal in 29.3% of personnel with asymmetry identified in 67.2%.

Biomechanics Summary: USASOC operators tended to land with greater hip and knee extension at initial contact. This strategy may place operators at an increased risk of injury by minimizing the effectiveness of larger muscles to provide dynamic joint stability upon impact. At the same point in landing operators also tended to have increased knee valgus angle which has been associated to the occurrence of knee injury by placing greater strain on ligamentous structures. Conversely USASOC operators also tended to utilize greater knee flexion throughout landing which can help decrease the risk of lower extremity injury by allowing the body to better absorb landing forces. It is likely because of this increased knee flexion that we also saw smaller peak vertical ground reaction forces compared to triathletes. However, the top 10th percentile of USASOC shows that better landing mechanics are achievable and they can further decrease landing forces, further lowering the risk of musculoskeletal injury.

Physiology

Body Composition

Testing Methodology:

BOD POD body composition tracking system

Purpose: Examine body composition (fat mass/fat-free mass)

Background: Physical performance can be improved by increasing the lean tissue mass (muscle) within the body, ultimately increasing strength and reducing the effects of fatigue due to excessive body mass and body fat. Similarly, too little body fat also has been shown to negatively affect athletic performance as low essential fat stores interfere with the normal physiological processes of the body, increase the risk of injury, and prolong injury recovery. Low body fat stores may decrease the available fuel to sustain prolonged training and combat missions. Additionally, the varying terrains and environmental conditions further support the importance of optimal body composition distribution. From a long-term health prospective, less body fat will decrease the risk of hypokinetic diseases (i.e., cardiovascular disease, diabetes, hypertension, hypercholesterolemia).

Data and Results:

	Body Fat (%)	Height (inches)	Weight (pounds)
Top 10th %tile 3SFG	9.2	--	--
Top 25th %tile 3SFG	12.9	--	--
50th %tile 3SFG	16.8	--	--
Bottom 25th %tile 3SFG	20.4	--	--
Athlete*	15.42	--	--
Triathletes	12.31 ± 4.37	--	--
USASOC (All)	18.15 ± 6.79	70.50 ± 2.63	187.41 ± 25.33
18 Series (3/5 SFG)	16.59 ± 5.57	70.54 ± 2.28	187.74 ± 23.31
SWCS (18 Series)	20.69 ± 5.42	70.45 ± 2.46	187.58 ± 22.88
Q-Course	12.52 ± 3.40	72.11 ± 2.30	184.46 ± 23.01
Pre Q-Course	14.98 ± 4.58	69.67 ± 3.90	175.54 ± 30.46
Support	21.24 ± 7.70	70.89 ± 2.49	192.42 ± 24.90
Other	22.64 ± 8.08	70.28 ± 2.30	193.29 ± 26.61

*NMRL Database of Professional Football Players

Ideal body composition for SOF to optimize physical and tactical readiness remains unknown. Complicated by environmental conditions and tactical requirements. Excessive body fat diminishes physical readiness and performance. Based on previous body composition and injury data collected on SOF, 15% body fat was identified as a threshold of marked increase in musculoskeletal injuries. At this established threshold, 22.2-85.7% of USASOC personnel were above 15% body fat.

Anaerobic Power/Anaerobic Capacity

Testing Methodology:

Velotron cycling ergometer (RacerMate, Inc., Seattle, WA)

Purpose: Examine anaerobic power/anaerobic capacity

Background: The development of lower extremity overuse injuries has been associated with low levels of physical fitness. Suboptimal levels of anaerobic power, along with other diminished physiological characteristics, as a result of non-scientifically structured training have been directly related to an increased risk of injury and impaired performance. Anaerobic power/anaerobic capacity is critical when high intensity, high stress bouts are followed by the need for tactical performance (e.g., gun firing).

Data and Results:

	Anaerobic Power (W/kg)	Anaerobic Capacity (W/kg)
Top 10th %tile 3SFG	16.0	9.3
Top 25th %tile 3SFG	14.9	9.0
50th %tile 3SFG	13.9	8.5
Bottom 25th %tile 3SFG	13.0	7.9
Athlete*	16.86 ± 1.35	10.45 ± 0.56
Triathletes	13.75 ± 1.05	9.25 ± 0.70
USASOC (All)	13.81 ± 1.33	8.09 ± 1.09
18 Series (3/5 SFG)	13.93 ± 1.42	8.41 ± 0.86
SWCS (18 Series)	14.01 ± 1.36	7.84 ± 1.00
Q-Course	14.65 ± 0.83	8.56 ± 0.89
Pre Q-Course	13.56 ± 1.15	8.35 ± 0.94
Support	13.59 ± 1.42	7.43 ± 1.26
Other	13.59 ± 1.13	7.58 ± 1.24

*NMRL Database of Professional Ice Hockey Players

Compared to the athlete model threshold, 55.6-94.4% of USASOC personnel were suboptimal for anaerobic power and 88.9-100% were suboptimal for anaerobic capacity. Anaerobic capacity demonstrated a negative relationship with body composition ($r = -0.62$).

Aerobic Capacity

Testing Methodology:

Viasys Oxycon Mobile portable ergospirometry system
Arkray LactatePro blood lactate test meter

Purpose:

Examine aerobic capacity ($\text{VO}_{2\text{max}}$ /lactate threshold)

Background: The development of overuse injuries has been associated with low levels of physical fitness. A significant relationship has been reported between less aerobically fit Operators and increased injuries as compared to Operators who are more fit. Suboptimal levels of maximal oxygen consumption and lactate threshold have been directly related to an increased risk of injury and impaired performance as premature fatigue results. Improvements in maximal oxygen consumption and lactate threshold with training will permit workout levels at higher intensities for longer durations without the accumulation of blood lactate to impair performance, while making the Operator more fatigue resistant.

Data and Results:

VO2

	VO2 max (ml/kg/min)	VO2 @ LT (ml/kg/min)	VO2 @ LT (% VO2 max)
Top 10th %tile 3SFG	55.6	46.1	89.8
Top 25th %tile 3SFG	51.6	40.5	86.1
50th %tile 3SFG	47.3	34.8	75.1
Bottom 25th %tile 3SFG	44.1	32.3	70.3
Triathletes	69.76 ± 7.29	58.20 ± 7.30	83.66 ± 8.52
USASOC (All)	46.97 ± 5.66	36.60 ± 5.99	78.09 ± 9.47
18 Series (3/5 SFG)	47.79 ± 5.10	36.73 ± 5.99	77.18 ± 9.33
SWCS (18 Series)	46.91 ± 5.57	37.69 ± 6.76	80.90 ± 10.82
Q-Course	51.29 ± 3.08	40.22 ± 4.20	78.68 ± 10.32
Pre Q-Course	48.58 ± 3.38	36.74 ± 4.88	75.21 ± 9.00
Support	45.65 ± 6.31	35.38 ± 7.02	77.57 ± 9.27
Other	43.75 ± 6.62	36.28 ± 5.42	82.13 ± 9.06

Compared to the athlete model, 100% of USASOC personnel were below threshold for aerobic capacity and 50-82.3% were suboptimal for lactate threshold. Aerobic capacity demonstrated a negative relationship with body composition ($r = -0.67$).

Nutritional Profiles

A nutritional analysis was performed for each subject through a nutrition/exercise history interview and a self-reported 24 hour dietary recall. Nutrition history included weight/body composition goals, physical training, eating habits, fluid consumption, frequency of foods, and supplement usage. Food/fluid habits relative to daily food consumption, prior to, during, and after physical training were compared to the profiles of an athletic population under similar physical demands. Data were analyzed to determine if the nutritional needs of operators were met in reference to total energy consumption, macronutrient distribution, and eating/hydration habits during physical training. Additionally, frequency of supplement usage and type were reported.

- Energy Requirements for Physical Training and Weight Goals
- Carbohydrate Requirements for Physical Training
- Protein Requirements for Increasing Muscular Strength and Endurance
- Distribution of Fat in the Diet
- Adequate Fluids During Exercise to Stay Hydrated and Maintain Energy
- Timing and Type of Post Physical Training Protein Intake
- Dietary Supplement Usage

Energy Requirements for Physical Training and Weight Goals

Testing methodology:

Nutrition/Exercise History and 24 hour Diet Recall (Phase 1)
Portable Respiratory Metabolic System (Phase 2)

Purpose:

To determine the amount of calories consumed on a daily basis and compare it to the calories required to fuel daily physical training as well as obtain the operators weight and body composition goals.

Background:

Energy expenditure data of military personnel reported in the literature has ranged from 3100 to over 8000 kcals per day. The large range reflects differences not only in the volume, intensity, operational and environmental demands of the physical activity being performed, but in the variety methods used to obtain the data. Although the daily total energy expenditure (TEE) of the students has not been quantified, estimations of energy needs can be calculated using reported physical activities and the Cunningham equation. The Cunningham equation uses fat free mass to calculate resting energy expenditure. TEE is then calculated by adding the estimated energy needs from physical activity to resting energy expenditure.

Weight Goals and Energy Intake

	USASOC Average BF 13.6±5.0%	3SFG Average BF 13.5±5.3%	QCourse Average BF 11.8±4.6%	SWCS Average BF NA	Pre QCourse Average BF 14.1±5.0%
<i>Want to gain weight</i>	15%	17%	38%	0%	22%
Consuming excess calories for weight gain	33%	33%	0%	--	62%
Consuming adequate calories to maintain weight	24%	22%	33%	--	13%
NOT consuming adequate calories to meet needs	42%	44%	67%	--	25%

	USASOC Average BF 21.9±6.5%	3SFG Average BF 20.0±6.5%	QCourse Average BF NA	SWCS Average BF 23.2±6.4%	Pre-QCourse Average BF 16.4±6.5%
<i>Want to lose weight</i>	42%	44%	0%	61%	19%
Consuming adequate calories for weight loss	59%	59%	--	64%	43%
Consuming adequate calories to maintain weight	16%	11%	--	9%	29%
Consuming excess calories	24%	30%	--	27%	29%

	USASOC Average BF 16.1± 5.6%	3SFG Average BF 15.3±5.6%	QCourse Average BF 12.6±6.9%	SWCS Average BF 20.5±6.7%	Pre-QCourse Average BF 14.9±5.56%
<i>Want to maintain current weight</i>	42%	38%	62%	39%	59%
Consuming adequate calories for weight maintenance	19%	20%	0%	14%	23%
Consuming excess calories	32%	30%	40%	0%	32%
NOT consuming adequate calories to meet needs	48%	50%	60%	86%	45%

Summary:

In order to gain weight, caloric intake must exceed daily total energy expenditure. Only a portion of Operators indicating a desire for weight gain consumed excess calories above nutritional requirements to fuel estimated energy needs. In fact, many Operators are not consuming adequate calories to maintain their current weight. Nearly half of these Operators are under consuming calories to meet basic needs and are instead promoting an environment for weight loss.

An environment in which total daily energy expenditure exceeds caloric intake is required to promote weight loss. Just over half of the Operators indicating a desire to lose weight were consuming adequate calories in order to do so. A portion of Operators were consuming the necessary amount of calories for weight maintenance and some, in excess. Consuming excess calories counter act the ability of the Operator to meet their goal of weight loss. These Operators should seek the advice of a Registered Dietitian to safely guide them through a meal plan to reach their goals while adequately fueling the demands of physical training.

Weight maintenance requires energy balance – total estimated energy expenditure is equal to caloric intake. Only a portion of Operators indicating a desire for weight maintenance consumed adequate calories to meet their estimated energy needs. Over a third of Operators were instead consuming excess calories which would promote weight gain. Nearly half of these Operators are not meeting energy needs, suggesting weight loss, impairment to physical performance, and increased risk for injury and illness.

Underreporting food intake, a limitation of self-reported food intake, may also contribute to the high number of individuals who have a recorded intake less than their estimated energy requirements.

****Important to note, that these are only estimates of energy expenditure based on a formula and not measured energy needs.**

Carbohydrate Requirements for Physical Training

Testing methodology:

Nutrition History and 24 hour Diet Recall

Purpose:

Carbohydrates should be provided based on training time and body weight in order to individualize specific muscle fuel needs for the Operators. The aim is to achieve carbohydrate intakes to meet the fuel requirements of the training program and to optimize restoration of muscle glycogen stores between workouts so that Operators are able to perform maximally and are combat ready more quickly.

Background:

Carbohydrate is the major fuel source for skeletal muscle and the brain. In the muscle, stored carbohydrate (glycogen) can be used for both anaerobic (short-term, high-intensity) and aerobic (endurance) activity. During prolonged strenuous physical activity, muscle glycogen and blood glucose are the major substrates for oxidative metabolism. Research has shown that CHO intake will also improve performance on military tasks.

Carbohydrate requirements will be estimated based physical training using the following:

Grams Carbohydrate/kg body weight/day

4-5 g/kg/day

5-7 g/kg/day

7-10 g/kg/day

10-12 g/kg/day

Training

Typical US Diet (low activity)

General training activities

Endurance athletes

Ultra endurance exercise (4-6 hr/day)

Data and Results:

Carbohydrate Requirements for Physical Training	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Met or exceeded the amount of carbohydrate in a typical US Diet (4-5 g/kg body weight/day)	33%	30%	25%	21%	62%
Met or exceeded the recommended amount of carbohydrate for general training needs (5-7 g/kg body weight/day)	19%	17%	25%	5%	43%

Summary:

When carbohydrate reserves are depleted during/after physical training and are not sufficiently replaced with adequate amounts of daily carbohydrate, there is a switch to a fat-predominant fuel metabolism which is characterized by muscle and central fatigue and the inability to maintain power output. Ultimately this results in a decrease in physical performance. In order for Operators to train at a higher level, it is vital they consume sufficient carbohydrates on a daily basis. The majority of Operators tested are currently not meeting the recommended amount of carbohydrate to optimally replace muscle glycogen or fuel muscles for higher intensity longer duration physical training.

Protein Requirements for Increasing Muscular Strength and Endurance

Testing Methodology:

Nutrition History and 24 hour Diet Recall

Purpose:

Examine protein intake as it relates to increasing muscular strength and power

Background:

A protein intake of 1.2-1.7 g/kg body weight should adequately meet the possibility for added protein needs during strenuous physical training. Protein requirement for strength trained individuals is on the higher side of the range (1.6-1.7g/kg body weight) allowing additional protein necessary to increase muscle mass, strength, and or power. Equally or more important to increase muscle strength and size is the provision of additional calories above the amount necessary for maintenance.

Protein Requirements: 1.2-1.7 g/kg body weight for endurance to strength trained athletes

Data and Results:

Protein Requirements for Increasing Muscular Strength and Endurance	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Fell within recommended protein requirements (1.2-1.7g/kg bw/day)	30%	37%	13%	16%	30%
Fell below recommended range for protein requirements <1.2 g/kg bw/day	34%	26%	25%	53%	22%
Exceeded recommended range for protein requirements (>1.8 g/kg bw/day)	31%	31%	63%	26%	46%

Summary:

There is a relatively even distribution among Operators who are meeting, falling below, or exceeding the range for protein requirements. Consuming between 1.2 and 1.7g per kg of body mass should adequately meet protein needs during strenuous physical training. Those Operators falling below the recommended range for protein intake are at risk for decreased body mass, muscle strength, size, and power output. For those Operators exceeding the recommended range for protein intake, excess protein may be replacing the intake of carbohydrates needed to properly fuel working muscle.

Data and Results:

Protein Requirements for Increasing Muscular Strength and Endurance	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Met protein requirements, exceeded estimated energy needs	5%	7%	0%	0%	14%
Met/exceeded protein needs, did NOT meet	40%	42%	50%	37%	19%

estimated energy needs					
Fell below recommended protein range, did NOT consume adequate calories	33%	35%	25%	53%	19%

In order to increase muscle strength and endurance, the right environment for weight gain and increasing muscle mass must be present. One in which protein requirements are met, and estimated energy needs are met or exceeded – very few Operators are meeting these requirements. Additionally, nearly half of these Operators were not meeting estimated energy needs - consuming suboptimal calories and protein will result in decreased body mass, muscle strength, size, and power output.

*Underreporting food intake may also contribute to the higher number of individuals who may have a reported intake less than their estimated energy requirements.

Distribution of Fat in the Diet

Testing Methodology:

Nutrition History and 24 hour Diet Recall

Purpose:

In order to maximize physical performance, it is essential to provide adequate calories, carbohydrate and protein in the diet. Once carbohydrate and protein needs are met, the balance of calories can be supplied by fat in the range of 0.8-1.0 g fat/kg body weight (moderate PT) to 2.0 g fat/kg body weight (heavy PT longer duration >4 hours/day).

Background:

Fat along with carbohydrate is oxidized in the muscle to supply energy to the exercising muscles. The extent to which these sources contribute to energy expenditure depends on a variety of factors, including exercise duration and intensity, nutritional status, and fitness level. In general as exercise duration increases, exercise intensity decreases and more fat is oxidized as an energy substrate. During high intensity physical training, predominantly carbohydrate is oxidized to fuel the muscles. To improve physical performance, individuals need to consume enough calories, carbohydrates, and protein to support the demands of training in order to train at a higher level. In planning a diet to provide the nutrients to support the training program, carbohydrate and protein needs are determined first and then the remaining calories are designated to fat which typically ranges from 0.8-2.0 g fat/kg body weight based on caloric needs, body composition goals and duration and intensity of training.

Data and Results:

Distribution of Fat in the Diet	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Consumed within recommended range for fat intake (0.8g to \leq 2.0g/kg/day)	61%	67%	75%	37%	49%
Consumed less than 0.8g fat/kg body weight/day	26%	25%	13%	30%	14%
Exceeded 2.0g fat/kg body weight/day	13%	8%	13%	5%	38%
Exceeded estimated energy requirements w/ highest fat consumption	13% (1.59-4.7g fat/kg)	10% (1.59-3.25g fat/kg)	25% (1.86-2.75g fat/kg)	--	30% (1.66-4.7g fat/kg)

Summary:

To train at an optimal level, it is important to consume sufficient calories, carbohydrates, protein and some fat. However, if foods high in fat replace carbohydrate and protein foods in the diet, such that these two macronutrients fall below recommended amounts, it may impair physical performance. It is recommended that Operators decrease the amount of fat in the diet and increase carbohydrate and protein foods (lower in fat) to better fuel their bodies for physical training and to improve body composition.

The majority of Operators fell within the recommended range for fat intake. Those operators who exceeded their estimated energy requirements also had the highest fat consumption and therefore may be missing essential nutrients for adequate fueling and muscle building/recovery.

From a health prospective, the Dietary Reference Intakes (DRIs) have defined an Acceptable Macronutrient Distribution Range (AMDR) for fat as 20-35% of daily energy needs for all adults. The AMDR is defined as a range in intakes for a particular energy source that is associated with reduced risk of chronic diseases while providing adequate intake of essential nutrients. Although the Dietary Reference Intakes (DRIs) specify a dietary fat intake range of 20-35% of total calories, for individuals who

are involved in daily hard physical training and are trying to acquire or maintain a lower body fat composition, consuming fat in the range of 20-30% may be more beneficial.

Data and Results:

Distribution of Fat in the Diet	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Consumed greater than 30% of calories from fat	71%	76%	88%	53%	76%

Summary:

The majority of Operators are currently consuming a diet that is >30% of calories from fat. High fat diets increase the risk for overweight, high body fat, high blood pressure, diabetes mellitus, and cardiovascular disease. Decreasing the overall fat content of the diet and replacing the calories with high carbohydrate, moderate protein foods (that are low in fat), would decrease health risk, enhance physical training, and improve body composition.

Adequate Fluids During Exercise to Stay Hydrated and Maintain Energy

Testing Methodology: Nutrition History

Purpose: Examine fluid habits before, during and after exercise

Background:

The goal is to provide adequate fluids to avoid dehydration but not in excess to avoid water intoxication. The Operator should be well hydrated when beginning exercise and accustomed to consuming fluid at regular intervals (with or without thirst) during training sessions to minimize fluid losses that may result in a decrease in physical performance. If time permits, consumption of normal meals and beverages will restore euhydration. Individuals needing rapid and complete recovery from excessive dehydration can drink approximately 1.5 L of fluid/kg of body weight lost (23 oz per pound). Consuming beverages and snacks with sodium will help expedite rapid and complete recovery by stimulating thirst and fluid retention.

Data and Results:

Consumed Fluids	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Before Physical Training	89%	95%	75%	88%	89%
During Physical Training	75%	85%	67%	71%	97%
After Physical Training	99%	100%	67%	100%	97%

Type of Fluids Before PT	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Water	81%	78%	89%	80%	73%
Other	15% (coffee, low fat milk, fruit juice)	15% (coffee, low fat milk, fruit juice)	11%	2% (coffee)	13%
Sports Drinks	4%	7%	0%	0%	13%

Fluids During PT	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Water	93%	91%	100%	92%	100%
Sports Drinks	4%	5%	0%	8%	6%
Other	3%	4%	0%	0%	0%

Fluids After PT	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Water	88%	81%	100%	94%	75%
Other	9%	13% (protein drink, fruit juice, coffee)	0%	0%	36%
Sports Drinks	3%	6%	0%	12%	14%

Summary:

The majority of Operators consume some fluid before physical training. The beverage of choice is water followed by “other” drinks. The majority of Operators also regularly drink fluids during PT. Water is the

preferred beverage; however, if PT lasts longer than 60 minutes, is rigorous, and/or is performed in a hot humid environment, it may be more beneficial to consume fluids with carbohydrates and electrolytes. Ideally, beverages consumed during training lasting longer than 60 minutes should contain 6-8% carbohydrate, 10-20 mEq sodium and chloride (constitution of most sports drinks). Sodium and carbohydrate help speed replenishment of fluid and energy reserves as well as replace sodium lost due to sweating.

The majority of Operators consumed fluids following physical training. Most drank water, followed by "other" drinks. Ideally, the beverage following physical training should contain fluid, carbohydrate, electrolytes and a small amount of protein. For example, low fat chocolate milk, fruit smoothie or sports drinks that contain protein are good choices. Water along with a snack or meal with carbohydrate, protein and electrolytes is also sufficient. Consuming a post exercise beverage or snack/meal containing carbohydrate and protein will provide the essential nutrients for faster muscle recovery and rehydration.

Timing and Type of Post Physical Training Protein Intake

Testing Methodology:

Nutrition History and 24 hour Diet Recall

Purpose: Examine protein intake and timing after physical training

Background: Immediately after (within 30 minutes) physical training, it is recommended to consume a snack/meal that contains both carbohydrate and a small amount of protein. Nutrient consumption with resistance training stimulates muscle protein synthesis and inhibits the exercise induced muscle protein breakdown, thereby muscle mass is gradually increased. Consuming a post exercise snack or meal containing carbohydrate and protein will provide the essential nutrients for faster muscle recovery. Expedited muscle recovery allows an individual to sustained higher physical work capacity (strength and endurance) in subsequent periods of exertion, thus increasing combat readiness.

Data and Results

Timing and Content of Pre-Training Snack	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Consumed pre-training meal or snack	49%	40%	100%	71%	65%
Pre-Training Type of Snack/Meal					
Contained both CHO and PRO	57%	30%	58%	57%	69%
Contained only PRO	9%	7%	8%	7%	3%
Contained only CHO	33%	20%	33%	36%	28%
N/A	1%	3%	--	--	--

Timing of Pre-Training Snack/Meal	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
< 30 min prior to PT	24%	20%	33%	25%	19%
30-60 min prior to PT	55%	64%	50%	58%	81%
1-2 hours prior to PT	16%	13%	17%	8%	0%
2-3 hours prior to PT	5%	2 %	0%	8%	0%
3-4 hours prior to PT	0%	0%	0%	0%	0%

Timing and Content of Post-Training Snack/Meal	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Consumed post-training snack/meal	92%	79%	100%	100%	89%
Post-Training Type of Snack/Meal					
Contained both CHO and PRO	81%	84%	57%	75%	86%
Contained only PRO	13%	12%	29%	25%	8%
Contained only CHO	6%	3%	14%	0%	6%

Timing of Post-Training Snack/Meal	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
< 30 min post PT	51%	51%	43%	47%	52%
30-60 min post PT	44%	46%	29%	47%	44%
1-2 hours post PT	4%	2%	29%	0%	0%
2-3 hours post PT	1%	0%	0%	6%	4%
3-4 hours post PT	1%	1%	0%	0%	0%

Summary:

Consuming food prior to PT will provide additional energy and may help to delay fatigue, allowing an Operator to perform for a longer duration and/or at a higher intensity for longer periods of time. In addition, including protein prior to exercise may help to minimize the catabolic effect of strenuous exercise on skeletal muscle.

The majority of Operators report eating a snack or a meal after the completion of physical training. Many consumed a snack/meal that contained both carbohydrate and protein. Ideally, consuming food that contains a moderate amount of carbohydrate and a small amount of protein within 30 minutes of activity will expedite muscle glycogen resynthesis and help to reduce muscle protein breakdown. This is especially important for those Operators/students/instructors participating in subsequent training bouts within 8 hours.

Dietary Supplement Usage

Testing methodology:

Nutrition History and 24 hour Diet Recall (Phase 1)

Purpose:

To determine the type and usage of dietary supplements.

Background:

The use of dietary supplements to promote health and improve physical performance has become increasingly popular among members of the military. The results of surveys indicate usage ranges from 37-81% (Institute of Medicine, 2008). Supplements available to service members range from those that might impart beneficial effects to health and performance with negligible side effects to other that have uncertain benefit and might be potentially harmful especially given the unique environmental and physical demands of military warfare. Currently, data on dietary supplement usage in special operation forces is lacking.

Data and Results

	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Operators that Report Taking at Least One Dietary Supplement	71%	73%	58%	94%	73%

Breakdown of Dietary Supplements	USASOC	3SFG	QCourse	SWCS	Pre-QCourse
Whey/Protein Supplements	18%	17%	19%	17%	33%
Energy Drinks/Caffeine	4%	4%	4%	2%	3%
BCAA, Amino Acids	8%	7%	15%	2%	17%
Fish Oil, Omega 3 FA, Antioxidants	16%	14%	22%	22%	11%
Glucosamine, Chondroitin, Joint Stability	8%	9%	7%	5%	9%
Creatine	3%	3%	0%	5%	3%
Pre-workout (Jack 3D/C4 Nitric Oxide, NO Explode)	4%	5%	0%	5%	4%
Weight Loss, CLA	1%	1%	4%	0%	0%
Testosterone Boosters	1%	1%	0%	0%	1%
Multivitamin/Minerals	31%	28%	26%	37%	14%
Carbohydrate Gels/Recovery	6%	9%	0%	2%	0%
Herbal Supplements, Probiotics	1%	4%	4%	2%	4%

The results of our survey indicate that of the majority of Operators indicate taking at least one dietary supplement, the most popular being a vitamin/mineral. A high percentage of operators are consuming a protein supplements, including Whey and/or BCAA. Consuming a meal with protein and carbohydrate before and after hard physical training will help to provide/replace used fuel stores and help rebuild

muscle more rapidly. A small percentage of Operators reported consuming a pre-workout supplement, such as Jack-3D, Nitric Oxide, or NO-Explode. The effectiveness of NO-Explode as an ergogenic aid is not supported by scientific literature nor have the safety issues been adequately addressed in the athletic or military populations. Previous formulas of Jack-3D contain Geranium Stem extract, which behaves like an amphetamine and when combined with caffeine, energy drinks, or other proprietary blend formulas can become a potent stimulant that may lead to serious injury or death. The Food and Drug Administration (FDA) has warned that DMAA is potentially dangerous to health and considers products containing it illegal. Geranium Stem is a banned substance on the NCAA, WADA supplement list, as well as being banned from military bases. The DOD has ordered an end to all on-base sales of supplements that contain DMAA (found in geranium stem extract).

Caution should be taken when consuming any dietary supplement, even vitamins/minerals. There is little, if any, regulation by the United States government on ingredients and formulas. A well balanced diet rich in fruits, vegetables, whole grains, lean protein, and healthy fats should provide adequate nutrients so that a dietary supplement is not needed.

Nutrition Summary

The majority of Operators tested did not meet the recommended amount of carbohydrate to optimally fuel 90-120 minutes of daily hard physical training (PT) and to restore muscle fuel for consecutive days of PT. Further, many Operators did not consume the recommended amount of carbohydrates for the (low active) "average adult male". Most Operators met the estimated protein requirements necessary to increase muscle size and strength. Over half of Operators consumed a diet that had >30% of calories from fat. If foods high in fat replace carbohydrate and protein foods in the diet, such that these two macronutrients fall below recommended amounts, it may impair physical performance and put Operators at risk for developing excess body fat. The majority of Operators consume fluids before, during, and after physical training. Similarly, a high percentage of Operators are consuming a meal or snack upon completion of physical training. Ideally, this meal or snack should contain both carbohydrate and a small amount of protein and be consumed within thirty minutes following exercise to expedite muscle glycogen resynthesis and reduce muscle protein breakdown. Only half of the Operators reported consuming a recovery snack/meal within 30 minutes following PT. The reported meal/snack did contain both carbohydrate and protein. Dietary supplement use was reported in 74% the Operators. Popular dietary supplements consumed include multivitamin/mineral, protein supplements, and fish oil/antioxidant supplements. A small percentage of Operators reported consuming some type of pre-workout supplement (including Jack-3D, C4, or NO-Explode). The effectiveness of these pre-workout supplements as ergogenic aids is not supported by scientific literature nor have safety issues been adequately addressed in the athletic or military populations. Based on self-reported dietary intake, the current data indicates a suboptimal macronutrient distribution to fuel and recover from daily hard PT. To optimize the adaptations from PT, it is recommended to increase daily carbohydrate intake and decrease fat, especially saturated fat. This will provide more energy to the Operator during PT and reduce the reliance on pre-workout aids and other dietary supplements that may be harmful.

Administrative

Personnel

This research project was a collaboration between personnel from the University of Pittsburgh and US Army Special Operations Command. Key personnel from each institution across the time duration of the project are listed below.

University of Pittsburgh	US Army Special Operations Command
John Abt, PhD, ATC	COL Pete Benson, MD
Scott Lephart, PhD	COL Shawn Kane, MD
Kim Beals, PhD, RD, CSSD	LTC Jeff Morgan, MD
Mita Lovalekar, PhD, MPH, MBBS	LTC Deborah Canada
Tim Sell, PhD, PT	LTC Matt Garber, PT
Julie Kresta, PhD	LTC Karen Daigle, RD
Anthony Bozich, MS, PT	Ray Bear, MS, ATC, CSCS
James Bakey, MS	

Human Subject Protections

Human subject protections were maintained by review boards from the University of Pittsburgh, Womack Army Medical Center, and higher level review performed by the Clinical Investigation Regulatory Office and Office of Research Protections, Human Research Protection Office.

University of Pittsburgh

The current protocol is approved through June 8, 2016. The principal investigator on this IRB was changed to Dr. Kim Beals. The approved protocol will be carried through for use on the pending grant submission.

Womack Army Medical Center

Phases 1-2: The current protocol is approved through March, 2016. COL Shawn Kane is the identified principal investigator. This protocol will be closed.

Phases 3-4: The current protocol is currently suspended. COL Shawn Kane is the identified principal investigator. This protocol will be revised and submitted to WAMC to re-activate the protocol.

Reportable Outcomes

Abstracts

Sell, TC, Abt JP, Lovaleker M, Bozich A, Benson P, Morgan J, Lephart SM, FACSM. Injury Epidemiology of US Army Special Operations Forces. *Medicine and Science in Sports and Exercise*. 46(5S):759-769, 2014.

Baker RA, Beals K, Darnell ME, Abt JP, Sell TC, Kane SF, Morgan JS, Benson PJ, Lephart SM. Dietary Protein Intake and Protein Supplement Use of United States Army Special Operations Command Operators. 2014 Food and Nutrition Conference and Expo - Academy of Nutrition and Dietetics Annual Meeting. October 18-21; Atlanta, GA.

Kane SF, Abt JP, Kresta JY, Bakey JF, Parr JJ, Sell TC, Lephart SM. Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Soldiers. American College of Sports Medicine Annual Meeting; May 26-30, 2015; San Diego, CA.

Abt JP, Eagle SR, Kresta JY, Bakey JF, Sell TC, Kane SF, Lephart SM. Identification of Asymmetrical and Suboptimal Agonist/Antagonist Strength in a Cohort of Special Forces Soldiers. American College of Sports Medicine Annual Meeting; May 26-30, 2015; San Diego, CA.

Manuscripts

Abt JP, Sell TC, Bozich AJ, Lovalekar MT, Kane SF, Benson PJ, Morgan JS, Lephart SM. Injury epidemiology of US Army Special Operations Forces. *Military Medicine*. 179(10): 1106-1112, 2014.

Parr JJ, Clark NC, Abt JP, Kresta JY, Keenan KA, Kane SF, Lephart SM. Residual impact of previous injury on musculoskeletal characteristics in Special Forces Operators. *Orthopaedic Journal of Sports Medicine*. In press.

Heebner NR, Abt JP, Lovalekar MT, Sell TC, Morgan JS, Kane SF, Benson PJ, Lephart SM. Physical and performance characteristics related to unintentional musculoskeletal injury in United States Army Special Forces: a prospective analysis. In preparation.

Kresta JY, Abt JP, Beals AK, Kane SF, Sell TC, Lephart SM. Physical readiness and musculoskeletal injury prevention in United States Army Special Forces Operators. In preparation.

Grant Submissions

USASOC Injury Prevention/Performance Optimization Musculoskeletal Screening Initiative. Submitted to US Army Medical Research and Materiel Command, W81XWH-BAA-14-1.

Conclusions

The three main objectives of this research were to 1) minimize the number and severity of Operator injuries, 2) maximize performance and combat readiness, and 3) enhance career longevity and quality of life following service. Several key findings have been established:

- Musculoskeletal injuries prevalent within SOF and higher frequency than conventional forces
- Majority of injuries are preventable
- Significant number of injuries sustained during physical training
- Operators sustaining musculoskeletal injuries demonstrated lower physical capacity
- Body composition and age influence physical and physiological characteristics and injury

Detailed conclusions can be found in Appendices 1-4.

References

1. Abt JP, Sell TC, Bozich AJ, Lovalekar MT, Kane SF, Benson PJ, Morgan JS, Lephart SM. Injury epidemiology of US Army Special Operations Forces. *Military Medicine*. 179(10): 1106-1112, 2014.
2. Parr JJ, Clark NC, Abt JP, Kresta JY, Keenan KA, Kane SF, Lephart SM. Residual impact of previous injury on musculoskeletal characteristics in Special Forces Operators. *Orthopaedic Journal of Sports Medicine*. In press.
3. Heebner NR, Abt JP, Lovalekar MT, Sell TC, Morgan JS, Kane SF, Benson PJ, Lephart SM. Physical and performance characteristics related to unintentional musculoskeletal injury in United States Army Special Forces: a prospective analysis. In preparation.
4. Kresta JY, Abt JP, Beals AK, Kane SF, Sell TC, Lephart SM. Physical readiness and musculoskeletal injury prevention in United States Army Special Forces Operators. In preparation.
5. Sell, TC, Abt JP, Lovaleker M, Bozich A, Benson P, Morgan J, Lephart SM, FACSM. Injury Epidemiology of US Army Special Operations Forces. *Medicine and Science in Sports and Exercise*. 46(5S):759-769, 2014.
6. Baker RA, Beals K, Darnell ME, Abt JP, Sell TC, Kane SF, Morgan JS, Benson PJ, Lephart SM. Dietary Protein Intake and Protein Supplement Use of United States Army Special Operations Command Operators. 2014 Food and Nutrition Conference and Expo - Academy of Nutrition and Dietetics Annual Meeting. October 18-21; Atlanta, GA.
7. Kane SF, Abt JP, Kresta JY, Bakey JF, Parr JJ, Sell TC, Lephart SM. Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Soldiers. American College of Sports Medicine Annual Meeting; May 26-30, 2015; San Diego, CA.
8. Abt JP, Eagle SR, Kresta JY, Bakey JF, Sell TC, Kane SF, Lephart SM. Identification of Asymmetrical and Suboptimal Agonist/Antagonist Strength in a Cohort of Special Forces Soldiers. American College of Sports Medicine Annual Meeting; May 26-30, 2015; San Diego, CA.

Appendices

1. Injury epidemiology of US Army Special Operations Forces.
2. Residual impact of previous injury on musculoskeletal characteristics in Special Forces Operators.
3. Physical and performance characteristics related to unintentional musculoskeletal injury in United States Army Special Forces: a prospective analysis.
4. Physical readiness and musculoskeletal injury prevention in United States Army Special Forces Operators.
5. Injury Epidemiology of US Army Special Operations Forces.
6. Dietary Protein Intake and Protein Supplement Use of United States Army Special Operations Command Operators.
7. Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Soldiers.
8. Identification of Asymmetrical and Suboptimal Agonist/Antagonist Strength in a Cohort of Special Forces Soldiers.

Injury Epidemiology of U.S. Army Special Operations Forces

John P. Abt, PhD*; Timothy C. Sell, PhD*; Mita T. Lovalekar, PhD*; Karen A. Keenan, PhD*; Anthony J. Bozich, MS*; LTC Jeffrey S. Morgan, MC USA†; COL Shawn F. Kane, MC USA†; COL Peter J. Benson, MC USA†; Scott M. Lephart, PhD*

ABSTRACT Musculoskeletal injuries have long been a problem in general purpose forces, yet anecdotal evidence provided by medical, human performance, and training leadership suggests musculoskeletal injuries are also a readiness impediment to Special Operations Forces (SOF). The purpose of this study was to describe the injury epidemiology of SOF utilizing self-reported injury histories. Data were collected on 106 SOF (age: 31.7 ± 5.3 years, height: 179.0 ± 5.5 cm, mass: 85.9 ± 10.9 kg) for 1 year before the date of laboratory testing and filtered for total injuries and those with the potential to be preventable based on injury type, activity, and mechanism. The frequency of musculoskeletal injuries was 24.5 injuries per 100 subjects per year for total injuries and 18.9 injuries per 100 subjects per year for preventable injuries. The incidence of musculoskeletal injuries was 20.8 injured subjects per 100 subjects per year for total injuries and 16.0 injured subjects per 100 subjects per year for preventable injuries. Preventable musculoskeletal injuries comprised 76.9% of total injuries. Physical training (PT) was the most reported activity for total/preventable injuries (PT Command Organized: 46.2%/60.0%, PT Noncommand Organized: 7.7%/10.0%, PT Unknown: 3.8%/5.0%). Musculoskeletal injuries impede optimal physical readiness/tactical training in the SOF community. The data suggest a significant proportion of injuries are classified as preventable and may be mitigated with human performance programs.

INTRODUCTION

Despite significant study of injury epidemiology in U.S. military personnel,^{1–5} limited published data have described injury patterns of U.S. Special Operations Forces (SOF).^{6–9} Anecdotal evidence provided by medical, human performance, and training leadership suggests musculoskeletal injuries continue to be a readiness impediment to SOF, including U.S. Army Special Operations Command (USASOC). The advanced tactical and physical requirements of USASOC personnel, and fiscal implications, including direct medical costs and manpower, of training USASOC personnel, highlight the importance of mitigating those musculoskeletal injuries with the potential to be preventable. Thus, it is critical to assess the extent of musculoskeletal injuries in this specialized community by describing injury epidemiology.

Musculoskeletal injuries in SOF have been previously identified in various SOF cohorts, and these injuries have a negative impact on force readiness.^{6–9} Naval Special Warfare (NSW) personnel sustained 0.9 to 3.2 injuries per 100 personnel per month (approximately 11 to 38 injuries per 100 personnel per year).⁸ Of these injuries, 21% of the diagnoses required surgery and had associated loss of time because of surgery and rehabilitation.⁸ Similarly, of 87 Marine Corps Special Operations personnel surveyed, 28 sustained at least one injury during a predeployment training cycle of approximately

12 months, resulting in 41 total injuries (approximately 47 injuries per 100 personnel per year).⁷ Of those injured, over 80% reported that their ability to train was hindered as a result of their injury. Although a similar statistic on injury frequency and severity is not available in USASOC Operators, based on all diagnoses encountered by U.S. Army 5th Special Force Group in the Armed Forces Health Longitudinal Technology Application (AHLTA) database, after “administrative” categories were excluded, roughly 40% of all diagnoses were related to musculoskeletal injuries.⁶ Those musculoskeletal injuries commonly involve back/neck, knee, shoulder, and ankle. Given the significance of musculoskeletal injuries sustained in SOF, further research is warranted to investigate injury frequency and severity in USASOC personnel in order to facilitate development of appropriate injury prevention training programs.

Consistent with the public health approach to injury prevention and control,¹⁰ the University of Pittsburgh human performance and injury prevention research with USASOC was initiated to support development of USASOC’s Tactical Human Optimization, Rapid Rehabilitation, and Reconditioning program. The first phase of the initiative is to collect injury data from the target population to understand the magnitude, nature, and impact of the injury problem.² Injury data, such as types of injuries, locations, and activities/mechanisms of injuries when injury occurred, would play an essential tool for clinicians and operators to understand injury epidemiology in their community. Further, because of limitations of automated database (AHLTA) and categories of injury diagnoses using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM), intricate information such as activities and mechanisms of injuries when injuries occurred have not been well examined in USASOC community. Therefore, the purpose of this analysis was to

*Department of Sports Medicine and Nutrition, Neuromuscular Research Laboratory, University of Pittsburgh, 3830 South Water Street, Pittsburgh, PA 15203.

†United States Army Special Operations Command (AOMD), 2929 Desert Storm Drive (Stop A), Fort Bragg, NC 28310.

The opinions, interpretations, conclusions, and recommendations are those of the author and not necessarily endorsed by the Department of Defense, U.S. Army, or U.S. Army Special Operations Command.

doi: 10.7205/MILMED-D-14-00078

describe the injury epidemiology of the 3rd SOF Group utilizing self-reported injury histories. Clinically, injury epidemiology could assist subsequent research phases in the model² and ultimately identify the priorities necessary for refinement of USASOC's physical training (PT) program to reduce musculoskeletal injuries and enhance force readiness.

METHODS

Human subject protections approvals were obtained by the appropriate necessary civilian and military review boards. Musculoskeletal injury data were captured from individual participant self-reports for a period of the prior 12 months and were obtained as a part of a comprehensive laboratory test protocol. Musculoskeletal injury data were one component of a comprehensive human performance research data collection consisting of biomechanical, musculoskeletal strength and flexibility, balance, physiological, and nutrition variables.²

Self-reported musculoskeletal injury data were collected on 106 male USASOC Special Forces Soldiers (age: 31.7 ± 5.3 years, height: 179.0 ± 5.5 cm, mass: 85.9 ± 10.9 kg, years of experience: 11.0 ± 5.5 years), from 3rd Special Forces Group (3SFG). Subjects were included in the University of Pittsburgh human performance and injury prevention research with USASOC if they were aged 18 to 60 years (inclusive); had no recent (3 month) history of traumatic brain injury, other neurological, or balance disorder; had no recent (3 month) history of upper/lower extremity or back musculoskeletal injury; had no history of metabolic, cardiovascular, or pulmonary disorder; and, were cleared for full and unrestricted duty. All subjects included in this analyses were enrolled as part of our larger research study with USASOC. Since assessment in the overall study requires laboratory testing that involves maximal physical exertion it was necessary that all subjects be free of musculoskeletal injuries in the 3 months prior to ensure prior musculoskeletal injury did not have any residual impact on the laboratory testing procedures. The total duration of injury query was based on 12 months before the laboratory data collection (3 months injury free buffer and 9 additional months).

Injury data were entered using a customized online application into a database, the University of Pittsburgh Military Epidemiology Database (UPitt-MED), by clinically trained research associates to ensure an accurate and thorough injury history. The UPitt-MED questionnaires included questions about injury anatomic location, anatomic sublocation, injury type, activity during which injury occurred, cause of injury, mode of onset of injury, mechanism of injury, and treatment received.

For the purposes of this analysis, an unintentional musculoskeletal injury was defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.) that, if occurring after enlistment, resulted in alteration in tactical activities, tactical training, or PT for a minimum of 1 day, regardless if medical attention was sought. If the injury occurred before enlistment, then the injury resulted in alter-

ation in activities of daily living and/or training/athletic activities for greater than 1 day, regardless if medical attention was sought. This includes conditions such as sprains, strains, and fractures (broken bones), but not contusions or lacerations (bruises and cuts).

Injuries were then further classified as preventable or not preventable. "Preventable injuries" are those musculoskeletal injuries that can be reduced through injury prevention programs that are developed to improve neuromuscular and physiological characteristics related to risk of musculoskeletal injury. Examples of preventable musculoskeletal injuries include lower extremity stress fractures resulting from running and/or marching and noncontact knee ligament injuries. "Not preventable injuries" are musculoskeletal injuries not able to be deterred through these injury prevention programs and includes injuries such as those sustained during motor vehicle accidents, direct contact, or stepping in a ditch. Other not preventable injuries include certain fractures, such as those to the face, fingers, or toes. The operational definitions of preventable and not preventable musculoskeletal injuries in this study are specific to our research group whose aim is to develop PT programs that improve modifiable neuromuscular and physiological characteristics related to risk of musculoskeletal injury. Although some of the injuries classified in this study as not preventable may be prevented through other intervention strategies, such as sleep modification, these injuries would not be preventable through PT programs.

Statistical Analysis

Self-reported injury data during a period of 1 year before the date of laboratory testing have been included in the injury description. Injuries were described using relative frequency (percent). The frequency of injuries was calculated as the number of injuries per 100 subjects per year. Injury incidence was calculated as the number of injured subjects per 100 subjects per year.

RESULTS

Self-reported injuries within a 1-year period before data collection have been described. The 106 subjects included in the analysis reported 26 injuries, including 20 preventable injuries, during a 1-year period.

Eighty-four subjects (84/106, 79.2%) did not report any injury during a 1-year period. Eighteen subjects (18/106, 17.0%) reported one injury, and four subjects (4/106, 3.8%) reported two injuries during a 1-year period. Eighty-nine subjects (89/106, 84.0%) did not report any preventable injury during a 1-year period. Fourteen subjects (14/106, 13.2%) reported one preventable injury, and three subjects (3/106, 2.8%) reported two preventable injuries during a 1-year period.

The frequency of injury for 3SFG subjects was 24.5 injuries per 100 subjects per year and injury incidence was 20.8 injured subjects per 100 subjects per year. The frequency of preventable

injury for 3SFG subjects was 18.9 injuries per 100 subjects per year and the injury incidence for preventable injuries was 16.0 injured subjects per 100 subjects per year. Preventable musculoskeletal injuries comprised 76.9% of injuries that occurred during the year before laboratory testing, for this 3SFG sample.

The anatomic location and sublocation of injuries are described in Figure 1 and Table I. The lower extremity was the most common location for injuries (13/26, 50.0%) and for preventable injuries (12/20, 60.0%). The shoulder and knee were common sublocations for injuries (each 6/26, 23.1%) and preventable injuries (each 5/20, 25.0%).

Data regarding the cause of injuries are described in Table II. Running and lifting were common injury causes. Running was the cause of 23.1% of injuries and lifting was the cause of 19.2% of injuries. When only preventable injuries were included in the analysis, running was the cause of 30.0% of preventable injuries and lifting was the cause of 25.0% of preventable injuries.

Data about activity when injury occurred are described in Table III and Figure 2. PT was the most reported activity for total injuries (PT Command Organized: 46.2%, PT Non Command Organized: 7.7%, PT Unknown: 3.8%) and preventable injuries (PT Command Organized: 60.0%, PT Non Command Organized: 10.0%, PT Unknown: 5.0%).

Injury types are described in Table IV. Common injury types for total injuries were sprain (6/26, 23.1%), fracture and strain (each 3/26, 11.5%). When only preventable injuries were analyzed, common injury types were sprain (6/20, 30.0%) and strain (3/20, 15.0%).

Musculoskeletal injuries were classified according to their onset as acute (18/26, 69.2% of injuries), overuse (7/26, 26.9%), and unknown onset (1/26, 3.8%). Among preventable injuries, 13 injuries (13/20, 65.0%) were acute and seven injuries (7/20, 35.0%) were overuse. Musculoskeletal injuries were classified according to their mechanism as contact injuries (10/26, 38.5% of injuries), noncontact injuries (15/26, 57.7%), and unknown mechanism (1/26, 3.8%). Among preventable injuries, five injuries (5/20, 25.0%) were contact injuries, 14 injuries (14/20, 70.0%) were noncontact injuries, and one injury (1/20, 5.0%) had an unknown mechanism.

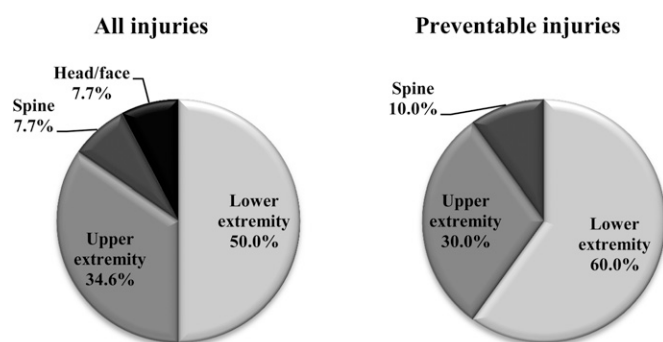


FIGURE 1. Anatomic location of injuries during a 1-year period.

TABLE I. Anatomic Sublocation of the Injuries During a 1-Year Period

Injury Anatomic Location	Anatomic Sublocation	All Injuries N (%)	Preventable Injuries N (%)
Lower Extremity	Knee	6 (23.1%)	5 (25.0%)
	Ankle	3 (11.5%)	3 (15.0%)
	Thigh	1 (3.8%)	1 (5.0%)
	Lower Leg	2 (7.7%)	2 (10.0%)
	Foot and Toes	1 (3.8%)	1 (5.0%)
Upper Extremity	Shoulder	6 (23.1%)	5 (25.0%)
	Upper Arm	1 (3.8%)	1 (5.0%)
	Hand and Fingers	2 (7.7%)	0 (0.0%)
Spine	Lumbopelvic	2 (7.7%)	2 (10.0%)
Head/Face	Eye	1 (3.8%)	0 (0.0%)
	Other	1 (3.8%)	0 (0.0%)
Total		26	20

TABLE II. Cause of Injuries During a 1-Year Period

Cause of Injury	All Injuries N (%)	Preventable Injuries N (%)
Running	6 (23.1%)	6 (30.0%)
Lifting	5 (19.2%)	5 (25.0%)
Cutting	3 (11.5%)	3 (15.0%)
Direct Trauma	3 (11.5%)	0 (0.0%)
Landing	2 (7.7%)	2 (10.0%)
Crushing	1 (3.8%)	0 (0.0%)
Fall—Same Level	1 (3.8%)	0 (0.0%)
Marching	1 (3.8%)	1 (5.0%)
Other	1 (3.8%)	1 (5.0%)
Unknown	3 (11.5%)	2 (10.0%)
Total	26	20

TABLE III. Activity When Injury Occurred During a 1-Year Period

Activity	All Injuries N (%)	Preventable Injuries N (%)
Combat	1 (3.8%)	0 (0.0%)
Motor Vehicle Accident	1 (3.8%)	0 (0.0%)
PT ^a —Command Organized	12 (46.2%)	12 (60.0%)
PT ^a —Non Command Organized	2 (7.7%)	2 (10.0%)
PT ^a —Unknown	1 (3.8%)	1 (5.0%)
Recreational Activity/Sports	3 (11.5%)	2 (10.0%)
Tactical Training	4 (15.4%)	3 (15.0%)
Other	2 (7.7%)	0 (0.0%)
Total	26	20

^aDenotes further classifications of PT as activity when injury occurred.

Musculoskeletal injury data were classified according to type of treatment sought following injury. Eleven injuries (11/26, 42.3%) required some type of diagnostic testing (magnetic resonance imaging, X-Ray or computed tomography scan). Ten injuries (10/26, 38.5%) required rehabilitation, 6 injuries (6/26, 23.1%) were prescribed pain medication, and 15 injuries (15/26, 57.7%) resulted in a prescription of rest. When preventable injuries were analyzed separately, six preventable injuries (6/20, 30.0%) required diagnostic testing. Ten preventable injuries (10/20, 50.0%) required rehabilitation,

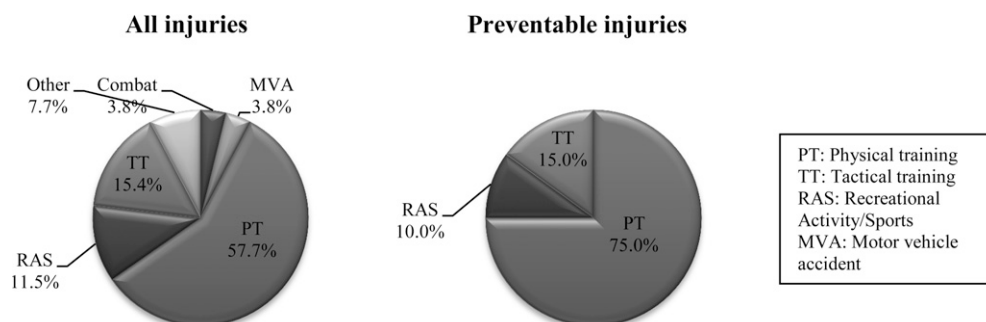


FIGURE 2. Activity when injury occurred during a 1-year period.

TABLE IV. Injury Type During a 1-Year Period

Injury Type	All Injuries N (%)	Preventable Injuries N (%)
Sprain	6 (23.1%)	6 (30.0%)
Fracture	3 (11.5%)	1 (5.0%)
Strain	3 (11.5%)	3 (15.0%)
Bursitis	2 (7.7%)	2 (10.0%)
Meniscal	2 (7.7%)	2 (10.0%)
Pain/Spasm/Ache	2 (7.7%)	2 (10.0%)
Concussion	1 (3.8%)	0 (0.0%)
Dislocation	1 (3.8%)	0 (0.0%)
Impingement	1 (3.8%)	1 (5.0%)
Inflammation	1 (3.8%)	1 (5.0%)
Tendonitis/Tenosynovitis/ Tendinopathy	1 (3.8%)	1 (5.0%)
Other	2 (7.7%)	1 (5.0%)
Unknown	1 (3.8%)	0 (0.0%)
Total	26	20

four preventable injuries (4/20, 20.0%) were prescribed pain medication, and 13 preventable injuries (13/20, 65.0%) resulted in a prescription of rest.

DISCUSSION

The objective of this analysis was to describe the self-reported injury epidemiology of 3SFG Soldiers for 1 year before laboratory testing at the Warrior Human Performance Research Laboratory. As part of a human performance and injury prevention research project, this analysis initially identified the specific musculoskeletal injury patterns within the U.S. Army SOF community. When compared with other SOF community, injury frequency and incidence rates are comparable and much less than those in the SOF trainees. Overall, a majority of musculoskeletal injuries occurred during PT and tactical training: they are preventable in nature. It implies that potential prevention strategies should focus on modifying PT and tactical training, especially involving running, lifting, cutting, and landing movements.

Injury Frequency and Incidence

In this investigation, the frequency of all musculoskeletal injury and injury incidence was 24.5 injuries per 100 subjects

per year and 20.8 injured subjects per 100 subjects per year, respectively. The injury frequency is comparable with the injury frequency sustained by NSW personnel (approximately 11 to 38 injuries per 100 subjects per year).⁸ A study by Linenger et al¹¹ conducted among U.S. Navy Sea-Air-Land (SEAL) trainees described medical conditions and musculoskeletal injuries during the SEAL candidacy training: This study revealed 29.7 cases of musculoskeletal injuries per 100 trainee-months (approximately 300 injuries per 100 subjects per year), which is higher than the injury frequency in this study. A higher injury frequency (approximately 47 injuries per 100 subjects per year) was also reported by Hollingsworth⁷ in Marine Corps Special Warfare personnel during a strenuous predeployment training cycle. There are potential explanations among studies: training phase, injury definition, and subject selection.

In both the Linenger et al¹¹ and Hollingsworth⁷ studies, injuries were described during specific training cycles, and perhaps higher frequencies of injuries were noted in both cases because certain injuries are more common during particular training cycles or evolutions. However, in this study, there was individual variability among subjects in phase of physical and tactical training depending on their missions in upcoming deployments.

In addition, definitions of injury are different among studies. For example, in the study by Hollingsworth,⁷ subjects were asked about pain or physical limitation because of musculoskeletal injury during the predeployment workup cycle. This definition is different from the definition used in our study, which defined an injury as a musculoskeletal injury that disrupted physical and/or training activities for at least 1 day whether or not medical attention was sought. The differences in injury frequency might be substantial as the majority of Marine Operators (19/28 Operators) with injuries continued their routine training regardless of injuries and reported no loss of training days. Injury frequency would likely be underestimated in this study.

This investigation is a part of comprehensive laboratory testing. Therefore, subjects must have met inclusion and exclusion criteria, which may have potentially excluded 3SFG Operators who suffered serious injuries from the study. Likely, those who suffer musculoskeletal injuries that are

severe enough might have been assigned to different units or services outside of the Special Forces community. That would likely mean that we tested some of the most resilient Operators who have been through many training, missions, and/or deployments without major injuries. Again, this would result in underestimation of actual injury counts.

Lauder et al¹² used data in a database for Army personnel in 1989–1994 to describe injuries related to sports and PT. Diagnoses were coded using the ICD-9-CM. The rate of sports injuries was 38 per 10,000 person-years for men. This incidence rate cannot be directly compared to the cumulative incidence calculated from this study, but both studies underscore the high risk of musculoskeletal injuries in the Army.

As a part of the University of Pittsburgh Injury Prevention and Performance Optimization research initiatives, we have conducted similar epidemiological analyses at two specific military populations: U.S. Army 101st Airborne Division (Air Assault) and NSW personnel.^{2,9} These studies revealed a high incidence of musculoskeletal injuries among 101st Division Soldiers and NSW personnel. In addition to injury frequency and incidence of musculoskeletal injuries, this study separated preventable and nonpreventable injuries. Preventable musculoskeletal injuries comprise the majority of injuries. These results substantiate efforts to reduce injuries through well-designed PT and combat training.

Anatomic Location and Sublocation

Comparison of the anatomic location and sublocation for injuries in this study to those reported in other literature is presented in Table V. In this study, injuries occurred most frequently in the lower extremity in the 3SFG. These data were consistent with Hollingsworth⁷ who reported that the lower extremity was the most injured region in Marine Corps Forces Special Operations personnel and with Peterson et al⁸ who identified a similar proportion of lower extremity injuries in NSW personnel. In contrast, Lynch and Pallis⁶ reported a lesser percent of injuries to the lower extremity in 5SFG. The primary anatomic sublocations of injury identified in this study were the knee and shoulder followed by the ankle. Hollingsworth⁷ also identified the knee as the most commonly injured body region followed by the low back and ankle. Contrary to these findings, Peterson et al⁸ and Lynch and Pallis⁶ reported that neck/back pain was the most common musculoskeletal in NSW personnel and the 5SFG, respectively. Both of these studies also reported the other frequently injured sublocations of injury as the ankle, shoulder, and knee; however, these sublocations were not in the same order.

Musculoskeletal injuries in NSW personnel also were described by our group.⁹ We described medical chart–reviewed as well as self-reported injuries. For medical chart–reviewed injuries, the anatomic location most frequently reported was the upper extremity followed by the lower extremity, spine, and torso. For self-reported injuries, anatomic location most

frequently reported was the lower extremity followed by the upper extremity, spine, torso, and head/face. The most common anatomic sublocation for medical chart–reviewed injuries was the shoulder and for self-reported injuries was the ankle and shoulder (each 16.7%). The injury distributions revealed in this study of 3SFG more closely resemble the self-reported data collected in the NSW study, with the highest proportion of self-reported injuries occurring in the lower extremity in both cases.

The results of this study of 3SFG are variable in comparison with investigations of injury location in other Army populations. Our research group conducted a study describing self-reported injuries among Army Soldiers in the 101st Airborne Division.² Bilateral injuries were counted twice in this report. The majority of injuries (62.6%) affected the lower extremity, which agrees with this study findings among 3SFG, where the majority of injuries (50.0%) also affected the lower extremity. In the study by Lauder et al,¹² the most commonly injured body parts were the knee and the ankle, with anterior cruciate ligament injury most common injury type in men. Although the most common anatomic location is similar to that in this study, shoulder injuries were the most common injury in the current study. The 3SFG Operators participate in more tactical training involving the upper extremity such as marksmanship training, rope climbing/repelling, lifting/loading/unloading, close-quarter combat with or without weapons, and skydiving training. Intensity and frequency of those training are likely related to more shoulder injuries when compared to the general forces.¹²

Types of Injuries and Acute/Overuse

In this investigation, sprain was the most common injury type (23.1%), followed by fracture and strain (each 11.5%). In our study of NSW Operators, among medical chart–reviewed injuries, strains (25.7%), pain/spasm/ache (20.0%), and fracture (11.4%) were common injury types. Among self-reported injuries, fracture (26.4%), sprain (13.9%), and strain (12.5%) were common injury types. In both this study and our investigation of 101st Airborne Division (Air Assault) Soldiers,² sprain was the most common injury type (22.2% of injuries in the study among 101st Airborne Division (Air Assault) Soldiers, and 23.1% in this study). The results from these investigations reveal consistent injury types. It is also related to how injuries occur. As discussed in the next paragraph, acute injuries are more common than overuse injuries.

The majority of musculoskeletal injuries in this study were classified as acute (69.2%), which is in accordance with previous reports. Hollingsworth⁷ reported a high proportion of traumatic injuries (54%) in a Marine Special Operations Company. Lauder et al¹² also demonstrated that for Army men and women combined, acute musculoskeletal injuries accounted for 82% of all injuries, and that acute injuries made up a greater proportion of injuries as compared to

overuse injuries. In the study by Linenger et al¹¹ of Navy SEAL trainees, overuse injuries accounted for >90% of all injuries, but in this study, acute injuries were more common. The fact that study by Linenger et al¹¹ was conducted among trainees may explain the higher frequency of injuries as well as a greater proportion of overuse injuries, as compared to this study that was not among trainees. The lower extremity was the most common location for injuries in both studies. This is important to note that the 3SFG Operators have been likely managing their training volume and rest cycles to avoid overuse musculoskeletal injuries. Given their age and years of service, the Operators learn the deployment cycles and specific training within each cycle.

Activities and Mechanisms of Injuries When Injuries Occurred

Military injury epidemiology studies have demonstrated that PT is a common activity during which musculoskeletal injuries frequency occur. This investigation revealed that of the injuries classified as preventable, 75% injuries occurred during PT (command organized, noncommand organized, or unknown). In our investigation of injuries in NSW personnel, subjects reported participation in training for 40.0% of medical chart-reviewed injuries and 56.9% of self-reported injuries. Previous work by our group investigated mechanism of injury in a group of 101st Airborne Division (Air Assault) Soldiers.² Like this study of 3FGS, this study found that training (PT, tactical training, or unspecified training) was the most common activity during which injuries occurred (48.5% of injuries in the study among 101st Airborne Division (Air Assault) Soldiers). Likewise, running was the most common cause of injury in both studies (34.3% of injuries in the study among 101st Airborne Division (Air Assault) Soldiers, and 23.1% in this study).

Our findings conflict with previous work by Lauder et al,¹² who described only injuries related to sports and PT using ICD-9-CM codes in Army personnel. In the case that an external cause of injury was recorded, only 11% of the subjects had injuries related to sports or PT. In contrast, this study included only men and was based on self-reported injury data not restricted to hospitalizations, and a much higher proportion of injuries (84.6%) was related to any type of training (physical or tactical) or recreational activity/sports in this study. This could be because injuries caused by training or sports in this young, active population typically are less likely to require hospitalization, causing a lower proportion of training injuries in the study by Lauder et al as compared to this study.

Limitations and Other Considerations

This investigation has limitations. The variability of injury frequency, incidence, anatomical location, type, and mechanism among studies may be explained by the variance in injury data collection methods utilized. Self-reported data

are prone to issues with the effect of recall. However, in our case, the self-reported method may have captured injuries that medical records may have missed because of perceived reduced severity, and lack of hospitalization or doctor visit. This investigation and the Hollingsworth study⁷ utilized self-reported survey, whereas Lynch and Pallis⁶ and Peterson et al⁸ utilized diagnostic categories (ICD-9CM) and medical record database. Understanding the differences between medical chart reviews and self-reports, and limitations of each collection method should be recognized.

CONCLUSION

PT is critical to the prevention of musculoskeletal injuries and optimization of human performance in SOF, yet a significant number of injuries are sustained during such training activities. The majority of these injuries are preventable. Musculoskeletal injuries affecting the lower extremity, and the frequency and severity of these injuries may negatively impact force readiness. Implementation of injury prevention and human performance programming is critical to maintenance of the most important weapons system platform—the Operator. Specifically, based on this investigation, reducing acute sprain/strain injuries during running, lifting, cutting, and landing during the centralized PT and tactical training should be focused through proper technique and training intensity/duration.

ACKNOWLEDGMENTS

This study was funded by the U.S. Army Medical Research and Materiel Command (Award No. W81XWH-11-2-0020) and the U.S. Army Research Laboratory (Award No. W911NF-10-1-0168).

REFERENCES

1. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S: Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med* 2010; 38(1 Suppl): S61–70.
2. Sell TC, Abt JP, Crawford K, et al: Warrior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part I. *J Spec Oper Med* 2010; 10(4): 2–21.
3. Jones BH, Bovee MW, Harris JM III, Cowan DN: Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993; 21(5): 705–10.
4. Shaffer RA, Brodine SK, Ito SI, Le AT: Epidemiology of illness and injury among U.S. Navy and Marine Corps female training populations. *Mil Med* 1999; 164(1): 17–21.
5. Jones BH, Cowan DN, Tomlinson JP, et al: Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc* 1993; 25(2): 197–203.
6. Lynch JH, Pallis MP: Clinical diagnoses in a special forces group: the musculoskeletal burden. *J Spec Oper Med* 2008; 8(2): 76–80.
7. Hollingsworth DJ: The prevalence and impact of musculoskeletal injuries during a pre-deployment workout cycle: survey of a Marine Corps special operations company. *J Spec Oper Med* 2009; 9(4): 11–5.
8. Peterson SN, Call MH, Wood DE, Unger DV, Sekiya JK: Injuries in naval special warfare sea, air, and land personnel: epidemiology and surgical management. *Oper Tech Sports Med* 2005; 13: 131–5.

9. Lovalekar M, Abt JP, Sell TC, et al: Descriptive epidemiology of musculoskeletal injuries in naval special warfare personnel. *Med Sci Sports Exerc* 2013; 45(5s): 63–6.
10. Powell EC, Sheehan KM, Christoffel KK: Firearm violence among youth: public health strategies for prevention. *Ann Emerg Med* 1996; 28(2): 204–12.
11. Linenger JM, Flinn S, Thomas B, Johnson CW: Musculoskeletal and medical morbidity associated with rigorous physical training. *Clin J Sport Med* 1993; 3(4): 229–34.
12. Lauder TD, Baker SP, Smith GS, Lincoln AE: Sports and physical training injury hospitalizations in the army. *Am J Prev Med* 2000; 18(3 Suppl): 118–28.

UNITED STATES POSTAL SERVICE® (All Periodicals Publications Except Requester Publications)

1. Publication Title: **MILITARY MEDICINE**

2. Publication Number: **249 - 160**

3. Filing Date: **10/1/2014**

4. Issue Frequency: **MONTHLY**

5. Number of Issues Published Annually: **12X**

6. Annual Subscription Price: **\$170 DOMESTIC/\$225 FOREIGN**

7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®):
**9320 OLD GEORGETOWN RD
 BETHESDA, MD 20814**

8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer):
SAME AS ABOVE

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank):
 Publisher (Name and complete mailing address):
**MIKE COWEN, M.D.
 9320 OLD GEORGETOWN RD, BETHESDA, MD 20814**
 Editor (Name and complete mailing address):
**WILLIAM H. J. HARTNER, M.D.
 9320 OLD GEORGETOWN RD, BETHESDA, MD 20814**
 Managing Editor (Name and complete mailing address):

10. Owner (Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)
 Full Name: **AMSUS**
 Complete Mailing Address: **9320 OLD GEORGETOWN RD, BETHESDA, MD 20814**

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box ☒ None

12. Tax Status (For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)
 The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☒ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months (Publisher must submit explanation of change with this statement)

PS Form 3526, July 2014 (Page 1 of 4 (see instructions page 4)) PSN: 7530-01-000-9931 PRIVACY NOTICE: See our privacy policy on www.usps.com

13. Publication Title: **MILITARY MEDICINE**

14. Issue Date for Circulation Data Below: **SEPTEMBER 2014**

15. Extent and Nature of Circulation

		Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)		6853	6881
b. Paid Circulation (By Mail and Outside the Mail)	(1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	6082	6089
	(2) Mailed In-County Paid Subscriptions Stated on PS Form 3541 (include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	0	0
	(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	212	270
	(4) Paid Distribution by Other Classes of Mail Through the USPS (e.g., First-Class Mail®)	0	0
c. Total Paid Distribution (Sum of 15b (1), (2), (3), and (4))		6294	9359
d. Free or Nominal Rate Distribution (By Mail and Outside the Mail)	(1) Free or Nominal Rate Outside-County Copies Included on PS Form 3541	402	422
	(2) Free or Nominal Rate In-County Copies Included on PS Form 3541	0	0
	(3) Free or Nominal Rate Copies Mailed at Other Classes Through the USPS (e.g., First-Class Mail)	0	0
	(4) Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	17	4
e. Total Free or Nominal Rate Distribution (Sum of 15d (1), (2), (3), and (4))		419	426
f. Total Distribution (Sum of 15c and 15e)		6713	6785
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))		140	96
h. Total (Sum of 15f and g)		6853	6881
i. Percent Paid (15c divided by 15f times 100)		94%	94%

* If you are claiming electronic copies, go to line 16 on page 3. If you are not claiming electronic copies, skip to line 17 on page 3.

PS Form 3526, July 2014 (Page 2 of 4)


UNITED STATES POSTAL SERVICE® (All Periodicals Publications Except Requester Publications)

16. Electronic Copy Circulation

	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Paid Electronic Copies	11	15
b. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a)	6294	9359
c. Total Print Distribution (Line 15f) + Paid Electronic Copies (Line 16a)	6713	6785
d. Percent Paid (Both Print & Electronic Copies) (16b divided by 16c × 100)	94%	94%

☐ I certify that 50% of all my distributed copies (electronic and print) are paid above a nominal price.

17. Publication of Statement of Ownership
☒ If the publication is a general publication, publication of this statement is required. Will be printed in the October 2014 issue of this publication. ☐ Publication not required.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner

 Date: **9/12/14**

I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

PS Form 3526, July 2014 (Page 3 of 4) PRIVACY NOTICE: See our privacy policy on www.usps.com

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Operators

Jeffrey J. Parr, PhD, ATC¹

Nicholas C. Clark, PhD, MSc, MCSP, MMACP, CSCS²

John P. Abt, PhD, ATC³

Julie Y. Kresta, PhD⁴

Karen A. Keenan, PhD, ATC¹

Shawn F. Kane, MD⁵

Scott M. Lephart, PhD³

¹University of Pittsburgh

Department of Sports Medicine and Nutrition

Pittsburgh, PA, USA

²St Mary's University

School of Sport, Health and Applied Science

Strawberry Hill, London, UK

³University of Kentucky

College of Health Sciences

Lexington, KY, USA

⁴Methodist University

Department of Physical Therapy

Fayetteville, NC, USA

⁵US Army Special Operations Command

Fort Bragg, NC, USA

Corresponding Author:

Jeffrey J. Parr, PhD, ATC

University of Pittsburgh

Neuromuscular Research Laboratory

3830 South Water Street

Pittsburgh, PA 15203

412-246-0460 (phone)

412-246-0461 (fax)

**Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces
Operators**

ABSTRACT

Background: Musculoskeletal injuries are a significant burden to United States Army Special Operations Forces. The advanced tactical skill level and physical training required of Army Special Operators highlights the need to optimize musculoskeletal characteristics to reduce the likelihood of suffering a recurrent injury.

Purpose: The purpose of this study was to identify the residual impact of previous injury on musculoskeletal characteristics.

Study Design: Descriptive laboratory study.

Methods: Isokinetic strength of the knee, shoulder, and back and flexibility of the shoulder and hamstrings were assessed as part of a comprehensive human performance protocol and self-reported musculoskeletal injury history was obtained. Subjects were stratified based on previous history of low back, knee, or shoulder injury and within-group and between-group comparisons were made for musculoskeletal variables.

Results: Knee injury analysis showed no significant strength or flexibility differences. Shoulder injury analysis found internal rotation strength of the healthy subjects (H) was significantly higher compared to the injured (I) and uninjured (U) limbs of the injured group (H: 60.8 ± 11.5 %BW, I: 54.5 ± 10.5 %BW, $p = 0.05$, U: 55.5 ± 11.3 %BW, $p = 0.014$). The external rotation/internal rotation strength ratio was significantly lower in the healthy subjects compared to the injured and uninjured limbs of the injured group (H: 0.653 ± 0.122 , I: 0.724 ± 0.121 , $p = 0.026$, U: 0.724 ± 0.124 , $p = 0.018$). Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (I: $111.6 \pm 9.4^\circ$, U: $114.4 \pm 9.3^\circ$, $p = 0.008$). The back injury analysis found no significant strength differences between the healthy and injured groups.

Conclusion: Few physical differences existed between Operators with prior knee or back injury. However, Operators with a previous history of shoulder injury demonstrated significantly less shoulder strength than uninjured Operators as well as decreased shoulder flexibility on the injured side. All Operators, regardless of prior injury must perform the same tasks; therefore a targeted injury, rehabilitation/human performance training, specifically focused on internal rotation strength and tightness of the posterior capsule, may help reduce the risk for recurrence of injury. Operators presenting with musculoskeletal asymmetries and/or insufficient strength ratios may be predisposed to musculoskeletal injury.

Clinical Relevance: Specific fitness programs to compensate for deficiencies in strength and flexibility need to be designed to reduce the risk of injuries in Special Forces Operators.

Keywords: muscle injury; residual; performance; injury prevention; military

What is known about the subject: Physical differences, such as, bilateral asymmetries and agonist:antagonist strength ratios are a risk factor for injury.

What this study adds to existing knowledge: Operators demonstrate bilateral asymmetries >10%, regardless if they presented with a prior injury, meaning both the healthy group and prior injury group are at risk for future injury based on suboptimal physical characteristics.

INTRODUCTION

Musculoskeletal injuries are a significant burden in the United States Army Special Operations Forces (ARSOF).^{18,25,26} Previous work from our laboratory found that the shoulder, knee, and low back were a significant problem with a high rate of injury in ARSOF.¹ Due to the high physical demand of ARSOF Operators training and operations, acute and overuse musculoskeletal injuries are the most common reason for medical clinic visits and missed duty days.²⁶ However, there is limited published data describing musculoskeletal characteristics of ARSOF Operators that have suffered prior injury. Deficits in strength and flexibility following injury may impede tactical readiness, reduce physical performance, and increase risk of suffering a subsequent injury.^{18,26} The advanced tactical skill level and physical training required to be an ARSOF Operator highlights the need to improve suboptimal musculoskeletal characteristics, regardless of injury history, in order to reduce the likelihood of suffering a future injury as well as to maximize tactical performance.

It is understood that deficits in musculoskeletal characteristics are risk factors for musculoskeletal injury. A study in professional soccer play took a subset of subjects who presented with preseason strength imbalances and put through a strengthening protocol to correct the strength imbalance.⁹ Once corrected, there was no difference in injury rates between the corrected strength imbalance group and the group who showed no muscular imbalance in the preseason.⁹ Following a musculoskeletal injury in an athletic population, it is recommended that an athlete not return to full sport participation until the injured musculature is at least 90% the strength of the contralateral uninjured musculature.¹⁰

Another variable found to influence performance among both athletic and military populations is flexibility. Several studies have found that posterior shoulder tightness is related to

shoulder impingement, rotator cuff injury, and labral tears.^{6,15,20,24,44} Manske et al., also found that posterior shoulder tightness was a limiting factor in shoulder internal rotation flexibility.²⁸ A study in military basic trainees found that increased hamstring flexibility decreased the overall number of lower extremity overuse injuries.¹⁷

If affected musculature is not properly rehabilitated following injury, the residual flexibility and strength deficits are thought to be a risk factor for future re-injury and early onset osteoarthritis;³⁸ therefore, impaired musculoskeletal characteristics as a result of past injury may be detrimental to the short-term physical readiness of ARSOF Operators and overall career longevity. While identifying characteristics associated with increased risk of musculoskeletal injury within the ARSOF community would be ideal to understand the mechanisms that produce injury, this is not always feasible. Little is known about the physical differences of Operators who have a previous history of musculoskeletal injury and those Operators who have not suffered a previous injury. The purpose of this study was to identify the residual impact of previous injury on current musculoskeletal characteristics.

METHODS

Operators were recruited through the Special Forces community via posted flyers, platoon briefings, and word-of-mouth. Operators who volunteered for testing participated in a standard protocol which included measures defined below. Prior to testing, all Operators read and signed the approved informed consent in accordance with civilian and military Institutional Review Boards. Demographic data were collected from Operators for age, race, and years of active duty experience. Also, a self-report history was performed for musculoskeletal injuries sustained from time of active duty status to study enrollment. A musculoskeletal injury was defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.) that

resulted in alteration in tactical activities, tactical training, or physical training for a minimum of one day, regardless if medical attention was sought. All injuries were recorded by a certified athletic trainer who had extensive training and experience in the field of sports medicine.

Participants

All Operators were recruited from the United States Army Special Operations Command. To meet inclusion criteria, all Operators must have (1) been between 18-55 years old, (2) been cleared for full active duty, (3) not sustained any musculoskeletal injuries in the last 3 months, (4) not sustained a traumatic brain injury or balance disorder in the last 3 months, (5) had no cardiac, pulmonary, or metabolic disorder and (6) not have exercised in the last 12 hours.

Injury Operational Definitions

Subjects were grouped as injured (shoulder/knee/lower back) or healthy. Injured subjects were defined at the time of this study as those that had any chart-documented history of injury to the specified anatomical location for which medical advice was sought. For shoulder and knee injuries we observed unilateral injury only – this was defined as past injury to only one side, and designated the injured side. The opposite side was designated the uninjured side. Subjects with bilateral injury were excluded from the analyses – this was defined as a chart-documented history of past injury to both sides of the body, even if at different time points. Healthy subjects were defined at the time of this study as those without any chart-documented history of injury to a specified anatomical location (shoulder/knee/lower back).

All injury types had standardized designations that were discussed and defined by experienced clinicians and researchers in our group in order to ensure validity and consistency of data. Shoulder injuries included all those that could be clinically localized to the shoulder region (e.g. impingement syndrome, acromioclavicular joint sprain). Knee injuries included all those

that could be clinically localized to the knee region (e.g. ligament sprain, patellofemoral pain). Lower back injuries included all those that could be clinically localized to the lumbosacral region (e.g. facet joint syndrome, muscle strain). Healthy subjects were defined at the time of this study as those without any chart-documented history of past injury to the specified anatomical locations.

Laboratory Data

Body Composition

Body composition was measured using the Bod Pod[®] (COSMED USA, Concord, CA). The Bod Pod[®] is an Air Displacement Plethysmograph that uses whole body densitometry to determine body composition. The Bod Pod[®] was calibrated and testing was performed in accordance with the manufacturer's instructions. Briefly, subjects were tested while wearing only tight fitting clothing (i.e. compression shorts) and an acrylic swim cap. Thoracic gas volume was estimated for all Operators using a predictive equation integral to the Bod Pod[®] software and body density was calculated internally using the appropriate density equation. Air displacement plethysmography has been found to be a reliable and valid method for measuring body composition in multiple populations.^{2,13,27,32}

Muscular Strength

Muscular strength was assessed by using the Biodex[®] System 4 Pro Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY) and Operators were stabilized according to the manufacturer instructions. Operators were tested for muscular strength in the shoulder (bilateral internal/external rotation), knee (bilateral flexion/extension), and trunk (flexion/extension). All practice and test trials were reciprocal concentric-concentric contractions

performed at 60°/s. Three warm-up trials were given at 50% of self-perceived maximum exertion and then three warm-up trials were given at 100% self-perceived maximum effort. The subject rested for one minute prior to performing five maximum test trials. The average peak torque (N-m) was normalized for body weight and used for data analysis. Muscular strength measured by isokinetic dynamometry has been found to be a reliable and valid method^{11,29,43} for measuring strength and has been used previously in our laboratory.^{31,41}

Flexibility

A digital inclinometer or standard plastic goniometer was used for all range of motion (ROM) measures. Range of motion was measured in both shoulders for passive internal rotation, external rotation, and posterior shoulder tightness. For lower extremity ROM, active knee extension (hamstring tightness) and active ankle dorsiflexion (calf tightness) were measured bilaterally. Alignment of the inclinometer and goniometer was performed based on previous research, which has been shown to have good intrarater reliability ($ICC \geq 0.85$).^{4,22,30} Briefly, the fulcrum of the goniometer was aligned with the axis of rotation for that joint, while the stationary and movements arms were aligned parallel to proximal and distal bony segments, respectively. A full description of our methods can be found in a previous paper.³⁹

Data Analysis

Descriptive statistics were calculated for demographic, body composition, strength, and flexibility variables. Data reduction procedures were performed before statistical analyses. Average peak torque values were normalized to bodyweight (% BW).⁴⁰ Shoulder external/internal rotation ratios were calculated by dividing external rotation values by internal rotation values. Knee flexion/extension ratios were calculated by dividing knee flexion values by knee extension values.¹⁴ Torso extension/flexion ratios were calculated by dividing trunk

extension values by trunk flexion values. Prior to statistical significance testing, normality of data was assessed with the Shapiro-Wilk test. For within-group side-to-side comparisons, paired t-tests were used for normally distributed data and Wilcoxon Signed Ranks tests for non-normally distributed data. For between-group comparisons, unpaired t-tests were used for normal distributions and Mann-Whitney tests for non-normal distributions. Statistical analyses were performed using SPSS 21 (SPSS Inc., Chicago). Significance levels were set a priori ($\alpha = 0.05$).

Clinical significance of data was also assessed. Based on previous work, threshold values were identified for reciprocal muscle group ratios: 0.7 for shoulder external/internal rotation,^{3,4,12} 0.6 for knee flexion/extension,¹⁴ 1.3 for torso extension/flexion.^{19,42} Ratios below these thresholds were considered clinically significant. Limb symmetry indices (LSI) were computed similar to other authors: $LSI (\%) = (\text{right side} \div \text{left side}) \times 100$.^{9,14} In line with previous work, a side-to-side difference $< 10\%$ was considered normal;^{14,37} a $LSI < 90\%$ or $> 110\%$ (i.e. $> 10\%$ side-to-side difference) was, therefore, defined as abnormal and considered clinically significant. Frequency counts were made of participants with reciprocal muscle group ratios below the previously identified threshold values along with participants with side-to-side differences $> 10\%$, and proportions [prevalence (%)] calculated. For the reciprocal muscle group ratio proportions, numerators were the total number of participants with sub-threshold values and denominators were the total number of participants in each anatomical region sample: prevalence (%) = (number of participants with sub-threshold ratio \div number of participants in the sample) $\times 100$.³⁶ For LSI proportions, numerators were the total number of subjects with side-to-side differences $> 10\%$ and denominators were the total number of participants in each anatomical region sample: abnormal LSI prevalence (%) = (number of participants with side-to-side differences $> 10\% \div$ number of participants in the sample) $\times 100$.³⁶

RESULTS

Demographic data for height, weight, percent body fat, and body mass index did not differ between injured and healthy Operators. Injury data reflects any injury incurred during active duty status up to three months prior to testing. Healthy is defined as the Operator not reporting any injuries during his active duty career. Age was significantly different between healthy and injured Operators with a previous history of shoulder injury ($p = 0.003$); however no differences were seen in any other group (TABLE 1).

Low Back

A total of 86 healthy and 20 injured (low back) Operators were included in this analysis. No significant strength differences were demonstrated between groups for trunk strength. Insufficient extension/flexion ratios, operationally defined as differences greater than 1.3, were identified in 18.6% of healthy subjects and 30% of injured subjects (TABLE 2).

Knee

A total of 51 healthy and 24 injured (knee) Operators were included in this analysis. Knee extension strength was significantly different between limbs of the healthy group (R: 231.59 ± 42.44 %BW, L: 224.73 ± 36.42 %BW, $p = 0.029$). No significant between limb or between-group differences in strength were demonstrated within the injured group. Asymmetry differences for knee flexion strength were identified in 45.1% of healthy subjects and 25% of injured subjects. Individual bilateral differences for knee extension were identified in 43.1% of healthy subjects and 25% of injured subjects. Insufficient knee flexion/extension ratio (<0.60) was identified in 43.1% of healthy subjects and 66.6% of injured subjects. No significant differences were demonstrated between limbs (injured) or between groups. Bilateral hamstring

flexibility was significantly different between limbs within the healthy group (R: $17.89 \pm 9.23^\circ$, L: $20.54 \pm 9.93^\circ$, $p < 0.001$) (TABLE 3).

Shoulder

A total of 53 healthy and 29 injured (shoulder) Operators were included in this analysis. Internal rotation strength of the healthy subjects was significantly higher (60.57 ± 11.54 %BW) compared to the injured (54.54 ± 10.45 %BW, $p = 0.05$) and uninjured limbs (55.54 ± 11.27 %BW, $p = 0.014$) of the injured group. The external rotation/internal rotation strength ratio was significantly lower in the healthy subjects (0.65 ± 0.12) compared to the injured (0.72 ± 0.12 , $p = 0.026$) and uninjured (0.72 ± 0.12 , $p = 0.018$) limbs of the injured group. Individual bilateral differences for internal rotation strength were identified in 45.3% of healthy and 44.8% of injured subjects. Individual bilateral differences for external rotation strength were identified in 35.8% for healthy subjects and 34.5% of injured subjects. Insufficient bilateral external rotation/internal rotation strength ratios (<0.70) were identified in 35.8% of healthy subjects and 31.0% of injured subjects. Internal rotation flexibility was significantly different bilaterally within the healthy group (R: $58.35 \pm 11.30^\circ$, L: $60.88 \pm 9.83^\circ$, $p = 0.040$). Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (Injured: $111.62 \pm 9.44^\circ$, Uninjured: $114.40 \pm 9.34^\circ$, $p = 0.008$). However, no significant differences were seen between groups with shoulder flexibility (TABLE 4).

DISCUSSION

Despite the high rate of musculoskeletal injuries suffered among ARSOF Operators, there is little published evidence describing the musculoskeletal characteristics of Operators with a history of musculoskeletal injury and those with no history of musculoskeletal injury.¹ The objective of this study was to determine the residual impact of previous injury on current

musculoskeletal characteristics. A review of the data within both the prior musculoskeletal injury group and no prior injury group revealed a higher proportion of subjects demonstrating a bilateral asymmetry >10%, regardless if they presented with a prior injury. This threshold is critical to reduce the risk of musculoskeletal injury and optimizing physical readiness.^{14,35,37} The large number of subjects presenting with musculoskeletal asymmetries, specifically strength-related asymmetries, may predispose Operators to additional injury. These scenarios may limit physical readiness at the individual and unit level.

Isokinetic strength testing revealed a suboptimal strength ratio between agonist and antagonist muscle groups in the low back (<1.30), knee (<0.60), and shoulder (<0.70). Operators with prior injury to the low back demonstrated an extension/flexion ratio which is closer to ideal (1.3) than their healthy cohorts. A focus of rehabilitation with low back pain typically focuses on increasing flexibility and strengthening the core.²³ This process of rehabilitation and the fear of re-injury could have led the injured group to more favorable habits within their physical training. Bilateral strength testing of the quadriceps and hamstring resulted in 66.6% of subjects in the injured group presenting with an insufficient knee flexion/extension ratio. A lower percentage of healthy subjects, 43.1%, also presented with an insufficient knee flexion/extension ratio. These abnormal knee extension/flexion ratios are associated with lower extremity injuries in an athletic population.²¹ Previous research using male participation found individuals with a greater than 10% difference between sides were at increased risk for injury.^{14,37} The Operators with prior history of injury tended to have decreased shoulder internal rotation strength compared to their healthy cohorts. Achieving an optimal agonist to antagonist muscular strength ratio is critical to the prevention of musculoskeletal injury^{7,34} as well as optimizing tactical readiness. Bilateral differences were not found in the shoulder, however, for knee flexion and knee extension

strength asymmetries were found in both healthy and injured subjects. The exact reason for the high proportion of bilateral asymmetries amongst Operators is not entirely understood. The authors hypothesize that a high proportion of bilateral asymmetries may be a result of greater emphasis being placed on the Operator's dominant side over a period of time. An Operator can be part of an actively deploying Special Forces team for several years and complete repetitive mission essential training on a regular basis during that time in order to consistently maintain or improve his level of tactical readiness. While repeatedly placing a greater amount of stress on the dominant limbs during tactical training (shooting, carrying loads, airborne operations, hand to hand combat training, etc.) over the course of a long duration of time it can be realistically proposed that natural adaptations, such as increased muscular strength, will occur due to the increased demands.

The injured Operator group showed bilateral asymmetries with posterior shoulder tightness. Several studies have indicated that posterior shoulder tightness can be a risk factor for future injury,^{20,24} and re-injury.¹⁶ While the Operators posterior shoulder tightness was not measured prior to injury and, therefore, it cannot be determined whether it was a reason for the previous injury, improper return to within normal limits (bilateral symmetry within 10%) can lead to future risk of re-injury. While no asymmetrical differences were seen bilaterally within the injured group, we did find significant bilateral differences with hamstring flexibility in our healthy group. Previous hamstring injury has been linked to deficits in proprioception, which is correlated with future risk of injury in both the hamstring and low back.^{38,41} Previous research in the military setting has found that implementing a hamstring flexibility protocol has decreased the risk of overuse injuries.¹⁷

A strength of this study is the large cohort of both injured and uninjured Operators. In addition, a within person comparison was able to be performed on each individual. A limitation of this study is that it was not possible to track which Operators performed physical therapy, how often, and if they had been discharged from their previous injury. The injury history of Operators was collected as a self-report which may present with certain advantages as well as certain limitations. The injury history was collected by a certified athletic trainer with extensive sports medicine training and a clinical background in preventing, diagnosing, and treating musculoskeletal injuries. This allows for more accurate recording of specific anatomical injury location and understanding of injury mechanisms. By nature of a self-report injury history, an Operator may have not recalled every injury he has suffered thus omitting injuries during the self-report history.⁸ However, past research has shown that individuals in overall good health, of younger age, and with higher education will more accurately report injuries. (REF) In addition, Operators do not always report injuries to medical so they can avoid being rolled from specialized schools, work-ups, and deployments. So a self-report may have allowed us to capture data that would not have been present in a medical chart review. Another limitation for this study is that Operators were excluded if they presented with an injury in the previous three-months. This may suggest that our group was tolerating their limitations without sustaining another injury.

Clinical Implications

This study agrees with other studies that a critical strength threshold, greater than 10%, in both previously injured and uninjured Operators bilaterally exist. This critical threshold places the Operator at risk for musculoskeletal injury during physical training and tactical mission operations.^{33,34} A large proportion of Operators in this study with previous history of injury

present with agonist:antagonist ratios that are considered suboptimal in the low back and knee. These suboptimal characteristics place the Operator at greater risk for future injury. These potential injuries may then affect the mission at both an individual and unit level, potentially causing changes in personnel, as well as the need for medical care. Identifying factors that cause bilateral asymmetries and suboptimal agonist:antagonist ratios in Operators will need to be examined, and better medical records on rehabilitation following injury will need to be tracked. While Operators are trained to perform all duties (weaponry, tactical maneuvers, etc.) bilaterally, a greater demand may be placed on the dominant side which potentially may lead to these asymmetries.⁴⁵ The authors recommend a specialized comprehensive fitness program to compensate for these deficiencies which will hopefully reduce the risk for injuries in Special Forces Operators. Previous research also has found several other interventions which may be beneficial. These include education for preventing overtraining, agility-like training, and nutrient replacement education.⁵

REFERENCES

1. Abt JP, Sell TC, Lovalekar MT et al. Injury epidemiology of U.S. Army Special Operations forces. *Mil Med.* 2014;179(10):1106-1112.
2. Ballard TP, Fafara L, Vukovich MD. Comparison of Bod Pod and DXA in female collegiate athletes. *Med Sci Sports Exerc.* 2004;36(4):731-735.
3. Bartlett LR, Storey MD, Simons BD. Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. *Am J Sports Med.* 1989;17(1):89-91.
4. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *Am J Sports Med.* 1988;16(6):577-585.
5. Bullock SH, Jones BH, Gilchrist J, Marshall SW. Prevention of Physical Training–Related Injuries. *American Journal of Preventive Medicine.* 2010;38(1):S156-S181.
6. Burkhart SS. Internal impingement of the shoulder. *Instr Course Lect.* 2006;55:29-34.
7. Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. *J Am Acad Orthop Surg.* 1998;6(4):237-248.
8. Coughlin SS. Recall bias in epidemiologic studies. *J Clin Epidemiol.* 1990;43(1):87-91.
9. Croisier JL, Ganteaume S, Binet J, Genty M, Ferret JM. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med.* 2008;36(8):1469-1475.
10. Drezner JA. Practical management: hamstring muscle injuries. *Clin J Sport Med.* 2003;13(1):48-52.

- 373 11. Drouin JM, Valovich-mcLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and
374 validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position
375 measurements. *Eur J Appl Physiol.* 2004;91(1):22-29.
- 376 12. Ellenbecker TS, Roetert EP, Piorkowski PA, Schulz DA. Glenohumeral joint internal and
377 external rotation range of motion in elite junior tennis players. *J Orthop Sports Phys*
378 *Ther.* 1996;24(6):336-341.
- 379 13. Fields DA, Goran MI, McCrory MA. Body-composition assessment via air-displacement
380 plethysmography in adults and children: a review. *Am J Clin Nutr.* 2002;75(3):453-467.
- 381 14. Grace TG, Sweetser ER, Nelson MA, Ydens LR, Skipper BJ. Isokinetic muscle
382 imbalance and knee-joint injuries. A prospective blind study. *J Bone Joint Surg Am.*
383 1984;66(5):734-740.
- 384 15. Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A
385 cadaveric model of the throwing shoulder: a possible etiology of superior labrum
386 anterior-to-posterior lesions. *J Bone Joint Surg Am.* 2005;87(4):824-831.
- 387 16. Hamilton GM, Meeuwisse WH, Emery CA, Steele RJ, Shrier I. Past injury as a risk
388 factor: an illustrative example where appearances are deceiving. *Am J Epidemiol.*
389 2011;173(8):941-948.
- 390 17. Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity
391 overuse injuries in military basic trainees. *Am J Sports Med.* 1999;27(2):173-176.
- 392 18. Hollingsworth DJ. The Prevalence and Impact of Musculoskeletal Injuries During a Pre-
393 deployment Workup Cycle: Survey of a Marine Corps Special Operations Comapany.
394 *Journal of Special Operations Medicine.* 2009;9(4):11-15.

- 395 19. Iwai K, Nakazato K, Irie K, Fujimoto H, Nakajima H. Trunk muscle strength and
396 disability level of low back pain in collegiate wrestlers. *Med Sci Sports Exerc.*
397 2004;36(8):1296-1300.
- 398 20. Kibler WB, Chandler TJ. Range of motion in junior tennis players participating in an
399 injury risk modification program. *J Sci Med Sport.* 2003;6(1):51-62.
- 400 21. Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and
401 flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J*
402 *Sports Med.* 1991;19(1):76-81.
- 403 22. Kolber MJ, Hanney WJ. The reliability and concurrent validity of shoulder mobility
404 measurements using a digital inclinometer and goniometer: a technical report. *Int J*
405 *Sports Phys Ther.* 2012;7(3):306-313.
- 406 23. Lindstrom I, Ohlund C, Eek C, Wallin L, Peterson LE, Nachemson A. Mobility, strength,
407 and fitness after a graded activity program for patients with subacute low back pain. A
408 randomized prospective clinical study with a behavioral therapy approach. *Spine (Phila*
409 *Pa 1976).* 1992;17(6):641-652.
- 410 24. Lintner D, Mayol M, Uzodinma O, Jones R, Labossiere D. Glenohumeral internal
411 rotation deficits in professional pitchers enrolled in an internal rotation stretching
412 program. *Am J Sports Med.* 2007;35(4):617-621.
- 413 25. Lovalekar M, Abt J, Sell T, Keenan K, Zimmer A, Lephart S. Descriptive Epidemiology
414 of Musculoskeletal Injuries in Naval Special Warfare Personnel. *Medicine and Science in*
415 *Sports and Exercise* 2013;45(5s):63-66.
- 416 26. Lynch JH, Pallis MP. Clinical Diagnoses in a Special Forces Group: The Musculoskeletal
417 Burden. *Journal of Special Operations Medicine.* 2008;8(2):76-80.

- 418 27. Malavolti M, Battistini NC, Dugoni M, Bagni B, Bagni I, Pietrobelli A. Effect of intense
419 military training on body composition. *J Strength Cond Res.* 2008;22(2):503-508.
- 420 28. Manske RC, Meschke M, Porter A, Smith B, Reiman M. A randomized controlled single-
421 blinded comparison of stretching versus stretching and joint mobilization for posterior
422 shoulder tightness measured by internal rotation motion loss. *Sports Health.*
423 2010;2(2):94-100.
- 424 29. McCleary RW, Andersen JC. Test-retest reliability of reciprocal isokinetic knee
425 extension and flexion peak torque measurements. *J Athl Train.* 1992;27(4):362-365.
- 426 30. Myers JB, Oyama S, Wassinger CA et al. Reliability, precision, accuracy, and validity of
427 posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med.*
428 2007;35(11):1922-1930.
- 429 31. Nagai T, Sell TC, House AJ, Abt JP, Lephart SM. Knee proprioception and strength and
430 landing kinematics during a single-leg stop-jump task. *J Athl Train.* 2013;48(1):31-38.
- 431 32. Noreen EE, Lemon PW. Reliability of air displacement plethysmography in a large,
432 heterogeneous sample. *Med Sci Sports Exerc.* 2006;38(8):1505-1509.
- 433 33. Orchard J, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sport*
434 *Med.* 2005;15(6):436-441.
- 435 34. Orchard J, Marsden J, Lord S, Garlick D. Preseason hamstring muscle weakness
436 associated with hamstring muscle injury in Australian footballers. *Am J Sports Med.*
437 1997;25(1):81-85.
- 438 35. Rahnama N, Lees A, Bambaecichi E. Comparison of muscle strength and flexibility
439 between the preferred and non-preferred leg in English soccer players. *Ergonomics.*
440 2005;48(11-14):1568-1575.

- 441 36. Rivara FP. *Injury control : a guide to research and program evaluation*. Cambridge ;
442 New York: Cambridge University Press; 2001, ix, 304 p. p.
- 443 37. Sapega AA. Muscle performance evaluation in orthopaedic practice. *J Bone Joint Surg*
444 *Am*. 1990;72(10):1562-1574.
- 445 38. Schmitt B, Tim T, McHugh M. Hamstring injury rehabilitation and prevention of reinjury
446 using lengthened state eccentric training: a new concept. *Int J Sports Phys Ther*.
447 2012;7(3):333-341.
- 448 39. Sell TC, Abt JP, Crawford K et al. Warrior Model for Human Performance and Injury
449 Prevention: Eagle Tactical Athlete Program (ETAP) Part I. *J Spec Oper Med*.
450 2010;10(4):2-21.
- 451 40. Sell TC, Abt JP, Crawford K et al. Warrior Model for Human Performance and Injury
452 Prevention: Eagle Tactical Athlete Program (ETAP) Part II. *J Spec Oper Med*.
453 2010;10(4):22-33.
- 454 41. Sell TC, Tsai YS, Smoliga JM, Myers JB, Lephart SM. Strength, flexibility, and balance
455 characteristics of highly proficient golfers. *J Strength Cond Res*. 2007;21(4):1166-1171.
- 456 42. Smith SS, Mayer TG, Gatchel RJ, Becker TJ. Quantification of lumbar function. Part 1:
457 Isometric and multispeed isokinetic trunk strength measures in sagittal and axial planes in
458 normal subjects. *Spine (Phila Pa 1976)*. 1985;10(8):757-764.
- 459 43. Sole G, Hamren J, Milosavljevic S, Nicholson H, Sullivan SJ. Test-retest reliability of
460 isokinetic knee extension and flexion. *Arch Phys Med Rehabil*. 2007;88(5):626-631.
- 461 44. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness
462 and motion loss in patients with shoulder impingement. *Am J Sports Med*.
463 2000;28(5):668-673.

- 464 45. Vairo GL, Duffey ML, Owens BD, Cameron KL. Clinical descriptive measures of
465 shoulder range of motion for a healthy, young and physically active cohort. *Sports Med*
466 *Arthrosc Rehabil Ther Technol.* 2012;4(1):33.

Title: Physical and Performance Characteristics Related to Unintentional Musculoskeletal Injury
in United State Army Special Forces: A Prospective Analysis

Authors:

Nicholas R Heebner, MS, ATC¹

John P Abt, PhD, ATC¹

Mita Lovalekar, MBBS, PhD, MPH²

Kim Beals, PhD, RD, CSSD²

Timothy C. Sell, PhD, PT²

Jeffrey S. Morgan, MD, MBA³

Shawn F. Kane, MD⁴

Scott M. Lephart, PhD¹

¹College of Health Science, University of Kentucky, Lexington, KY, USA

²Neuromuscular Research Laboratory, University of Pittsburgh, Pittsburgh, PA, USA

³Womack Army Medical Center, Fort Bragg, NC, USA

⁴US Army Special Operations Command, Fort Bragg, NC, USA

Word Count: 6008 / 6000 (With abstract and ref)

Background: Musculoskeletal injuries are serious and often an under recognized concern within military forces. Recent epidemiological data collected on US Army Special Forces Operators demonstrated that 76.9% of injuries were preventable musculoskeletal injuries and support the use of an injury prevention and performance enhancement program. However, population specific characteristics related to injury must first be identified.

Hypothesis/Purpose: To determine which characteristics are predictive of musculoskeletal injury and may be useful for screening procedures in US Army Special Forces Operators.

Study Design: Prospective Cohort Study

Methods: A total of 95 US Army Special Forces Operators participated in this study (age = 32.7 ± 5.1 years, height = 179.8 ± 6.9 cm, weight = 89.9 ± 12.7 kg). Laboratory testing included body composition, aerobic and anaerobic capacity, upper and lower body strength and flexibility, balance, and biomechanical testing. Injury data were captured for a period of twelve months following laboratory testing. Injury frequencies and cross-tabulations were calculated to evaluate the relationships between measured physical characteristics and injury proportions. Odds ratios were calculated to further evaluate the usefulness of each physical characteristic as a risk factor for injury.

Results: Injured operators demonstrated significantly less trunk strength and knee position during landing in comparison with uninjured operators. Trunk strength was also diminished in the sub-group of spine-injured operators. Knee position at initial contact was also significantly less in operators who experienced a lower extremity injury and those who experienced a spine

injury. Operators who fell into the bottom 25th percentile on knee, shoulder and/or trunk strength were over two times more likely to have sustained an injury.

Conclusions: This study showed that decreased knee, shoulder, and trunk strength are risk factors for subsequent musculoskeletal injury in Army Special Forces operators. The accumulation of two or more of these risk factors results in higher proportions of injured operators.

Clinical Relevance: Injury prevention initiatives in Special Forces should focus on identifying and correcting deficits in knee, shoulder, and trunk strength, aerobic capacity, and knee position during landing. Specific individualized training programs targeting these characteristics are necessary to maintain force health and readiness.

Key Terms: Injury, Military, Strength, Flexibility, and Biomechanics

What is known about the subject: Military personnel, especially Special Forces (SF) operators, experience increased incidences of musculoskeletal injuries due to physical training that directly impact force readiness. Modification of training to improve risk factors for musculoskeletal injury has been shown to decrease injuries in other military population. However, population specific characteristics still need to be identified through prospective risk factor analysis.

What this study adds to existing knowledge: This study identifies physiological, physical, and biomechanical characteristics that are prospectively shown to be risk factors for musculoskeletal injuries in SF operators.

INTRODUCTION

Musculoskeletal injury due to training and recreation is a serious and often under-recognized problem in military populations.¹⁻⁴ These injuries place a large burden on our military personnel and can directly affect the readiness of special operations forces across various branches of service.⁴⁻⁸ Epidemiology data have demonstrated that a significant proportion of musculoskeletal injuries seen in basic military forces and in the special operations forces (SOF) community occur during training and are classified as preventable.^{4,5} These studies have defined preventable injuries as those that can be reduced through the use of injury prevention programs by improving characteristics related to musculoskeletal injury.⁵ Musculoskeletal injuries occurring within the SOF communities have demonstrated high incidence rates and have a negative impact on force readiness. Leadership also recognizes that this high incidence and recurrence of injury may negatively affect quality of life after service.

Physical training is a critical part of enhancing physical and occupational performance in SOF groups, yet a large proportion of injuries seen in these groups are directly related to training.^{7,9,10} A recent epidemiological evaluation of injuries within the United States Army Special Forces has demonstrated injury rates up to 20.8% of operators per year, of which 76.9 are preventable musculoskeletal injuries.⁵ This highlights a need for an injury prevention and performance enhancement training program to combat the large amount of musculoskeletal injuries seen during training. Continual evaluation and modification of current injury prevention and performance enhancement programming is needed to combat these injuries still seen in the population and subsequent impact on individual and force readiness. Such training programs, such as the Tactical Human Optimization, Rapid Rehabilitation and Restoration (THOR3), are in

place and have the capability to be modified for individual needs and to accomplish both injury prevention and human performance optimization.

The successful application of an injury prevention and performance enhancement initiative has shown long-term implications for improving the suboptimal characteristics leading to injury, potentially improving career longevity of the Soldier.¹¹ Previous reports have suggested that programs designed to prevent injury and optimize performance in the military are valid and effective.^{4,11} However, prior to the application of a clinical trial, the population specific modifiable characteristics that are related to future incidence of injury must first be identified. Therefore, the purpose of this study was to determine physiological, musculoskeletal, and biomechanical characteristics that may be risk factors for musculoskeletal injuries in United States Army Special Forces Operators. It was hypothesized that physiological performance, strength, flexibility, balance, and biomechanical characteristics would show significant differences between injured and uninjured groups and significant relationships with future musculoskeletal injury. The identification of modifiable risk factors for future injury is critical for the development of effective injury prevention initiatives aimed toward the reduction of avoidable musculoskeletal injury during service, preservation of operators' career longevity, and quality of life after service. Additionally, knowledge of what characteristics are risk factors for injury it is also possible develop a predictive formula to screen candidates or cadets that are enrolling in the selection process for the SOF community and may be at greater risk of developing injuries.

MATERIALS AND METHODS

Human subject protections approvals for the study procedures and data handling were obtained by the appropriate civilian and military review boards. A total of 190 United States

Army Special Forces operators took part in this study. Their demographic information is listed in Table 1. Baseline data collection procedures consisted of physiological, musculoskeletal strength and flexibility, biomechanical and balance characteristics. Medical records were queried for any injury that occurred during a twelve-month time period following baseline laboratory testing.

Procedures

Physiological Testing

Body composition was measured using the Bod Pod® Body Composition System (Cosmed, Inc, Chicago, IL). Using air displacement plethysmography to measure body volume and calculate body density based on the subject's weight. Subjects were required to wear spandex/compression shorts and a swim cap while seated in the pod. Appropriate densitometry equations were used with predicted lung volumes.¹² Our laboratory has demonstrated excellent reliability for this procedure (ICC = 0.98, SEM = 0.47% body fat).¹³

The Velotron cycling ergometer (RacerMate, Inc, Seattle, WA) and Wingate protocol was used to measure peak anaerobic power and capacity during a maximal effort trial.¹⁴ Each subject was fitted to the cycle ergometer by adjusting the seat and handlebar position prior to a five-minute self-paced warm-up. The subject began the test by maintaining a 100 rpm pace at 125 watts for fifteen seconds. After the fifteen second preparatory phase the subject had five-seconds to sprint as fast as they could before the electromagnetic brake of 9% of their body weight was applied and sustained for thirty seconds. Subjects were instructed to pedal as hard and as fast as they could throughout the entire braking phase and received verbal encouragement throughout the test. Peak anaerobic power and capacity were define as the maximum wattage and

mean wattage, normalized to body weight, throughout the thirty-second braking phase. This procedure has been previously determined to be both valid and reliable.¹⁵

Maximal oxygen consumption was measured during a modified incremental maximal treadmill protocol using a TrueOne® metabolic system (Parvo Medics, Sandy, UT).¹⁶ Prior to the test subjects performed a five-minute warm up at 75% of their self-reported last two-mile APFT test pace. The test was performed at 90% of this pace. The test began at 0% treadmill incline and was increased by 2% grade every three minutes until volitional fatigue. Verbal encouragement was given throughout the test. VO₂max was calculated as the highest one minute average during the test and normalized to body weight (mL/min/kg). VO₂max have been previously reported as reliable and predictive of aerobic fitness in US Army trainees.¹⁷

Musculoskeletal Assessment

Isokinetic strength of torso flexion and extension, shoulder internal and external rotation, shoulder protraction and retraction, shoulder elevation, and knee flexion and extension were assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY). All measures were completed using the manufacturer's guidelines and collected bilaterally when appropriate. The mean normalized peak torque (Nm/kg) across five reciprocal trials was used as the measure of strength. Knee extension and flexion strength tested on the Biodex have been previously shown to excellent reliability (ICC = 0.96, SEM = 12.7 %BW and ICC = 0.98, SEM = 9.3 %BW, respectively).¹⁸ Shoulder internal and external rotation strength has demonstrated good reliability (ICC = 0.79, SEM = 5.2 and ICC = 0.784, SEM = 5.8 %BW, respectively).¹⁹ Pilot data collected in our research facility has demonstrated good to excellent reliability for shoulder protraction - retraction and torso flexion – extension (ICC = 0.83 – 0.93, SEM = 16.8 – 47.2 %BW and ICC = 0.92 – 0.98, SEM = 12.4 – 13.5 %BW, respectively). Ankle

inversion and eversion isometric strength was assessed with a handheld dynamometer using a break protocol. Three trials were collected and averaged together to calculate the mean isometric ankle strength toward inversion and eversion (% body weight).

Range of motion during flexibility testing was measured using a digital inclinometer. Flexibility of shoulder internal/external rotation and hip extension were assessed using methods described by Norkin and White²⁰ and been shown to have good to excellent reliability (ICC = 0.824 – 0.935, SEM = 3.25° and ICC = 0.855, SEM = 2.318°).¹⁹ To measure posterior shoulder tightness subjects were in the supine position with should abducted and elbow flexed to ninety degrees. The examiner blocked movement of the scapula with one hand and with the other horizontally adducted the humorous. The excursion of the humorous relative to the trunk in degrees was measured. This measure of posterior shoulder tightness has been demonstrated to have excellent reliability (ICC = 0.94, SEM = 1.8°).²¹ Active knee extension was measured with the subject in a supine position and the hip and knee bent to ninety degrees. The subject was then asked to straighten the knee as far as possible while one examiner stabilized the thigh and another examiner measured knee flexion in degrees. This measure of hamstring flexibility has been shown to have excellent reliability (ICC = 0.901, SEM = 4.208°).¹⁹ Three trials were completed for all flexibility measures and averaged across trials.

Biomechanical and Balance Assessment

Biomechanical characteristics during double and single-leg landings were measured while subjects performed a double-leg stop-jump task and a single-leg drop-landing task. The double-leg stop-jump task required subjects to perform a forward broad jump over a distance equal to 40% of their body height, land on a 40 x 60 cm force platform, and upon landing immediately perform a maximal vertical jump. The single-leg drop-landing task required

subjects to begin by standing on one leg on top of a 45.7cm platform, drop off the platform, and land on the same leg on the force platform. This test was completed bilaterally. Retro-reflective markers (14mm) were placed throughout anatomical landmarks of the subject's lower extremity and pelvis according to Vicon's Plug-in-Gait biomechanical model (Vicon, Centennial, CO).²² Anthropometric measurements such as height, weight, leg length, and knee and ankle widths were entered into the data collection software (Nexus v1.8, Vicon, Centennial, CO) and used for estimations of joint centers and segment parameters for the biomechanical model.^{23,24} Raw marker trajectory data was collected using a high-speed infrared camera system composed of six cameras (T-Series, Vicon, Centennial, CO) collecting at a sampling frequency of 200 Hz. Ground reaction forces were measured using two force platforms (Kistler 9286A, Amherst, NY) that were flush with the surrounding ground surface and collected at a sampling frequency of 1200 Hz. The Plug-in-Gait biomechanical model was used for kinematic calculations. Use of this model and system has been shown to be a valid and reliable methods of three-dimensional kinematic analysis of the lower extremity (CMC = 0.611 – 0.983). Maximum and initial contact knee joint angles, along with peak vertical ground reaction forces were averaged across three trials using a custom Matlab® script (The MathWorks inc., Natick, MA). Trials were discarded and repeated if the subjects did not land completely on the force platform.

Dynamic postural stability was assessed during a single-leg landing task as described by Sell et al.²⁵ Subjects were asked to perform a forward double-leg jump from a distance of 40% of their height, land on one leg, and obtain balance as fast as possible. A custom Matlab® script was used to calculate the dynamic postural stability index (DPSI) and medial-lateral stability index (MLSI) as described by Wikstrom et al.²⁶ This method of assessing dynamic postural stability has been shown to have good to excellent reliability (ICC = 0.86, SEM = 0.01). This

procedure was completed on both legs. The Sensory Organization Test (SOT) using a NeuroCom® Balance Manager® system (SMART Balance Master, Natus Medical Inc., San Carlos, CA) was also used to assess standing postural stability under varying conditions. Subjects were asked to stand on both feet (barefoot) and the examiner aligned their feet on the platform according to the manufacturer's recommendations. This test consisted of three trials at each of the six conditions within the SOT test battery (SOT1: eyes open, SOT2: eyes closed, SOT3: eyes open – reactive surround, SOT4: eyes open – reactive surface, SOT5: eyes closed – reactive surface, SOT6: eyes open – reactive surface and surround) The SOT has been shown to have moderate reliability in a young healthy population ($ICC = 0.67$).²⁷

Prospective Injury Data

Injury occurrence tracked using ICD-9-CM coded medical encounter data that were obtained for the study subjects. ICD-9-CM codes that were identified as relevant to our research were analyzed further, other codes were deleted. The outcome was a relevant ICD-9-CM code (relevant injury) that occurred during a period of 365 days after laboratory data collection. Separate analyses were conducted for the following outcome variables: All injuries, Lower extremity injuries, Spine injuries, Upper extremity injuries

Statistical Analysis

All statistical procedures were performed using SPSS (version 22, IBM, Armonk, NY). Descriptive statistics were calculated for all variables and normality was assessed using Shapiro Wilk Tests. Frequencies and cross tabulations were used to examine proportion of injured subjects. Between group differences (Injured group, uninjured group) were assessed using appropriate student t-tests or Mann-Whitney-U tests. To further evaluate each variable as a

potential risk factor for injury, cut-off values were determined for each variable. The bottom 25th percentile value of each respective variable was used for all cut-off values except for body fat percentage because previous research has demonstrated that general Army Soldiers with greater than 18% body fat demonstrate decreased physical performance.¹³ Cut-off values are listed in Table 3. Odds ratios and corresponding 95% confidence intervals were calculated. Odds ratios were considered statistically significant if the 95% confidence interval did not include 1.00. Lastly, a risk factor count score was calculated for each subject that was the sum of characteristics in which they fell below the 25th percentile. Only characteristics that displayed significant odds ratios were counted for this analysis. Statistical significance was set to $p < 0.05$ *a priori*.

RESULTS

Group Comparison

Out of a total of 95 participants 47 (49.5%) went on to sustain an injury during the twelve-month period following baseline testing. Lower extremity injuries were the most common (39.4%) followed by spine and upper extremity injuries (Table 1 and Figure 1). All descriptive statistics and results of normality testing and between group comparisons are reported in Table 2. Flexibility and balance results were unable to show any between group differences for the all injuries group or any subgroup. Operators who sustained an injury demonstrated significantly less trunk strength for both trunk extension (273.05 vs 321.59 %BW, $p = 0.036$) and trunk flexion (186.21 vs 200.08 %BW, $p = 0.048$). Landing biomechanics also revealed significant between group differences as operators who sustained injuries demonstrated significantly less right knee flexion at initial contact (23.6 vs 26.6°, $p = 0.049$), however, left knee data was not significant (24.3 vs 25.1°, $p = 0.623$). Despite the lower knee flexion angle at initial contact,

operators who sustained an injury showed significantly less right vertical ground reaction forces during single-leg drop-landings (559.4 vs 610.3 %BW, $p = 0.025$).

Among the lower extremity (LE) injury sub-group, trunk strength and some landing kinematics were different between groups. The Operators who sustained a LE injury demonstrated significantly lower trunk flexion strength values (181.00 vs 197.56 %BW, $p = 0.032$). Additionally, right knee varus angle at initial contact during stop-jumps (8.0 vs 4.6° , $p = 0.011$) and drop-landings (1.6 vs -0.3° , $p = 0.006$) were significantly greater in operators who sustained a LE injury.

Upper extremity (UE) injury sub-group showed only one significant difference from the uninjured group and that was age. Operators who subsequently went on to develop or sustain an upper extremity injury were significantly older (35.0 vs 30.5 years, $p = 0.039$). Lastly, the spine injured sub-group showed several between group differences. Operators who developed a future spine injury had significantly decreased VO₂max scores than those without spine injuries (44.3 vs 47.6 mL/min/kg, $p = 0.013$). These operators also had significantly higher BMI than those who did not have a spine injury (27.84 vs 26.14 , $p = 0.013$). Left knee extension strength was also significantly weaker among the spine-injured group than those without a spine injury (205.57 vs 225.28 , $p = 0.036$).

Risk Factor Analysis

To further assess the measured characteristics of these operators as potential risk factors for injuries, odds ratios were calculated for the injured group and for each of the injury sub-groups (Table 3). Strength characteristics at the knee and shoulder yielded significant odds ratios ranging from 2.215 to 5.689. Operators who fell into the bottom 25th percentile for knee strength

were 2.215 times more likely to sustain any injury and between 3.263 and 5.689 time more likely to sustain a lower extremity injury. Operators in the bottom 25th percentile of left shoulder retraction strength were 4.952 times more likely to sustain a spine injury and those in bottom 25th percentile of the of right shoulder internal rotation range of motion were 3.208 time more likely to sustain a spine injury.

There is an inverse relationship between proportion of subjects injured vs uninjured as the sum of risk factors increase (Figure 2). The distribution of injured to uninjured operators with a risk factor count score equal to zero was 32% injured and 68% uninjured. However, there were a greater proportion of operators in the injured group with a risk factor count score equal to one (65% vs 35%) and increased to 100% injured with a risk factor count score of four.

DISCUSSION

Identification of population specific modifiable characteristics is critical for the implementation of injury prevention initiative. The purpose of this study was to determine which physiological, musculoskeletal, and biomechanical characteristics are predictive of musculoskeletal injury and may be useful for screening procedures in US Army Special Forces Operators. It was hypothesized that these measured characteristics would be related to increased incidence of injury and was partially supported by the results of this study. The comparison between injured and uninjured groups did reveal some between group differences in strength and landing biomechanics. Injury frequency and odds ratio analysis revealed eight modifiable characteristics as potential risk factors for injury including knee extension and flexion strength, trunk flexion strength, and knee flexion position at initial contact. Additionally, an inverse relationship was found between the risk factor count score and proportion of injured subjects.

Comparison of injured and non-injured operators revealed that operators who went on to sustain an injury had significantly less trunk flexion and extension strength. After creating subgroups based on injury type this study still found that operators who sustained a lower extremity injury had significantly less trunk flexion strength and less knee extension strength compared to those that did not sustain a lower extremity injury. Trunk and knee strength were also important in spine injuries. Operators who sustain a spine injury also had significantly less trunk flexion and knee extension strength. Strength deficits at the knee have been shown to be a contributor in different injury types and athletic performance.²⁸⁻³⁰ Previous research has also shown that defects in trunk strength are related to injury and back pain in collegiate wrestlers.³¹ This same relationship also has been demonstrated in golfers.³² Knee extensor strength is an important component for injury prevention in US Special Forces.

Injured operators also used significantly less knee flexion at initial contact during landing. Landing with less knee flexion angle at initial contact have been shown to lead to increased joint loading is considered to be a risk factor for some lower extremity injuries.³³ However, this study did not show any significant group difference in knee flexion angle at initial contact when examining lower extremity injuries alone. Although differences in knee flexion at initial contact was not significant when examining the sub group of lower extremity injury, knee valgus angle at initial contact was significant. Operators who sustained lower extremity injury landed in significantly more knee valgus than those who did not sustain a lower extremity injury. This is in contrast to previous research that suggests increased knee valgus angle is a risk factor for lower extremity acute and chronic injury.³⁴⁻³⁶ However, these studies mainly use a female athletic population. Additionally, the results of this study still demonstrate that landing in a more neutral knee alignment may be protective against lower extremity injury.

Other characteristics such as BMI and VO2max were also different between groups but only for the subgroup of spine injuries. Operators who sustained a spine injury had significantly greater BMI than those that did not. BMI and previously been established as a risk factor among various musculoskeletal injuries including spine injuries.³⁷⁻⁴⁰ Additionally, VO2max was also significantly less in operators who sustained a spine injury. Although VO2max may not have a direct physiological link to spine injury it has been shown to be predictive of athletic performance. US Special Forces operators are required to work certain intensity despite physiological limitation such as VO2max. Operators with higher BMI and lower aerobic capacity compared to other may be at an increased risk of injury.

To the author's best knowledge this is the first study to prospectively evaluate differences between injured and uninjured military personnel and establish musculoskeletal characteristics as risk factors for injury in US Special Operation Forces operators. Sell et al.⁴ previously established risk factors for musculoskeletal injury in US 101st Airborne Air Assault Army Soldiers by comparing Soldier baseline data to healthy elite level triathletes.⁴ This study found that 101st Soldiers had strength deficits in knee, shoulder, and ankle; flexibility deficits in the shoulder, and physiological deficits in BMI, body fat percentage, anaerobic power, anaerobic capacity, and aerobic capacity. Although this study by Sell et al. provided a unique analysis and comparison that demonstrates sub-optimal performance in this military cohort, the current study was also able to highlight prospective differences between operators who went on to be injured and those that did not. Dvorak et al.⁴¹ conducted a similar study investigating risk factors for injury in football athletes but did not include measures of strength, flexibility, balance, or biomechanics.⁴¹ They did find that individuals who were injured had significantly lower body fat percent.⁴¹

The current study identified three modifiable characteristics that demonstrate how operators with deficits in these areas compared to their peers have a higher likelihood of becoming injured. Operators who were in the bottom 25th percentile in strength measures for knee extension strength, shoulder retraction strength, and shoulder internal rotation range of motion had 2.215 to 5.689 times the risk of becoming injured compared to operators who ranged above the bottom 25th percentile. However, no physiological, strength, flexibility, balance, or biomechanical characteristics demonstrated higher odds of sustaining an upper extremity injury for those who fell in the bottom 25th percentile. It was expected to observe more relationship between characteristics and injury, however, this may be due to the fact that the current study utilized ICD-9 code for lower extremity musculoskeletal injuries. Also, the current study grouped injuries by gross location together because further separation into specific injuries or sub-locations did not provide a large enough sample size for appropriate analyses.

Another interesting finding from the current study was the relationship between the risk factor count score and the increase in proportion of injured operators. As the risk factor count score increased there was a greater proportion of injured than uninjured subjects. This finding suggests that operators who fall in the bottom 25th percentile in multiple characteristics were at a greater risk of suffering an injury. A previous study in US Army Rangers also determined that the possession of multiple risk factors increases the likelihood of sustaining an injury.⁴² Dvorak et al.⁴¹ also found a similar relationship in elite level football players: the greater amount of risk factors present the greater proportion of injured players.⁴¹ This finding is very important for human performance and medical staff to assess and consider individualized training and rehabilitation to target deficits related to peer performance.

Previous studies aimed at identifying risk factors for musculoskeletal injuries in military populations have commonly found body composition measures such as BMI a risk factor for injury.^{37,39} However, the current study did not find that body fat percentage as a risk factor for injury and was only able to find difference in BMI in the spine injury group. Teyhen et al.⁴² performed a similar prospective risk factor analysis using BMI in United State Army Rangers and found no difference between Soldiers who sustained an injury and those that did not.⁴² This discrepancy between research studies may be due to the observed population. Soldiers required to perform at a higher level of physical standard such as SOF operators may be less susceptible to injuries related to larger BMI or body fat percentage due to training. However, increased body fat percentage is related to decreased performance and thus is still recommended to be optimized in future efforts to maximize force effectiveness.¹³

Limitations

There are some limitations associated with this study. This study tracked musculoskeletal injuries over a twelve-month period using ICD-9-CM codes reported in each operator's medical chart. Although this method of injury and disease tracking is widely used and accepted, causes and mechanisms for injuries are often not reported.^{1,3,9,43,44} Because of this, the investigators were not able to report or categorize based on specific injury mechanisms. Despite the use of ICD-9-CM diagnosis codes and large grouping of injuries, significant odds ratios were still found. Lastly, this data was collected on US Army Special Forces operators; therefore, generalizability of these findings may be limited to the SOF community and may not align well with general military forces. Military groups with different injury patterns and demands may find different risk factors. Population and demand specific training and injury prevention is a critical

consideration for human performance and rehabilitation in the military and needs to be considered in future studies.

Conclusion

The findings of this study demonstrate the importance of optimizing knee extension strength, trunk strength, and knee position upon landing in preventing musculoskeletal injuries in US Army Special Forces Operators. Operators with a deficit in knee extensor strength were significantly more likely to sustain a lower extremity. This study also identified shoulder retraction strength and shoulder internal rotation deficits also contribute to higher likelihood of sustaining an injury. Additionally, the accumulation of risk factors seems to compound the risk of sustaining injuries. These findings highlight the need for individualized screening and training that focuses on identification and correction of musculoskeletal and performance deficits relative to their peers. Future studies are needed to validate such training interventions in this specific population.

REFERENCES

1. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal Injuries: Description of an Under-Recognized Injury Problem Among Military Personnel. *American journal of preventive medicine*. 2010;38(1):S61-S70.
2. Jones BH, Bovee MW, Harris JM, 3rd, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med*. 1993;21(5):705-710.
3. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, Frykman PN. Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc*. 1993;25(2):197-203.
4. Sell TC, Abt JP, Crawford K, et al. Warrior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part I. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals*. 2010;10(4):2-21.
5. Abt JP, Sell TC, Lovalekar MT, et al. Injury epidemiology of u.s. Army special operations forces. *Military medicine*. 2014;179(10):1106-1112.
6. Hollingsworth DJ. The prevalence and impact of musculoskeletal injuries during a pre-deployment workup cycle: survey of a Marine Corps special operations company. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals*. 2009;9(4):11-15.

7. Lovalekar M, Abt JP, Sell TC, Keenan K, Zimmer A, Lephart SM. Descriptive epidemiology of musculoskeletal injuries in naval special warfare personnel. *Med Sci Sports Exerc.* 2013;45(5s):63-66.
8. Shaffer RA, Brodine SK, Ito SI, Le AT. Epidemiology of illness and injury among U.S. Navy and Marine Corps female training populations. *Military medicine.* 1999;164(1):17-21.
9. Lynch JH, Pallis MP. Clinical Diagnoses in a Special Forces Group: The Musculoskeletal Burden. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals.* 2008;8(2):76-80.
10. Peterson SN, Call MH, Wood DE, Unger DV, Sekiya JK. Injuries in Naval Special Warfare Sea, Air, and Land Personnel: Epidemiology and Surgical Management. *Operative Techniques in Sports Medicine.*13(3):131-135.
11. Sell TC, Abt JP, Crawford K, et al. Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part II. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals.* 2010;10(4):22-33.
12. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. *Nutrition.* 1993;9(5):480-491; discussion 480, 492.
13. Crawford K, Fleishman K, Abt JP, et al. Less body fat improves physical and physiological performance in army soldiers. *Military medicine.* 2011;176(1):35-43.
14. Smith JC, Hill DW. Contribution of energy systems during a Wingate power test. *Br J Sports Med.* 1991;25(4):196-199.
15. Bar-Or O. The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Medicine.* 1987;4(6):381-394.
16. Kang J, Chaloupka EC, Mastrangelo MA, Biren GB, Robertson RJ. Physiological comparisons among three maximal treadmill exercise protocols in trained and untrained individuals. *European journal of applied physiology.* 2001;84(4):291-295.
17. Sharp MA, Patton JF, Knapik JJ, et al. Comparison of the physical fitness of men and women entering the U.S. Army: 1978-1998. *Med Sci Sports Exerc.* 2002;34(2):356-363.
18. Keskula DR, Dowling JS, Davis VL, Finley PW, Dell'omo DL. Interrater reliability of isokinetic measures of knee flexion and extension. *Journal of athletic training.* 1995;30(2):167-170.
19. Sell TC, Tsai YS, Smoliga JM, Myers JB, Lephart SM. Strength, flexibility, and balance characteristics of highly proficient golfers. *Journal of strength and conditioning research / National Strength & Conditioning Association.* 2007;21(4):1166-1171.
20. Norkin CC, White DJ. *Measurement of joint motion: A guide to goniometry.* 2nd ed: F. A. Davis Company; 1995.
21. Myers JB, Oyama S, Wassinger CA, et al. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med.* 2007;35(11):1922-1930.
22. Vicon. Plug-In-Gait: Foundation Guide - Foundation Notes. <http://www.vicon.com>; Vicon Motion Systems LTD; 2008.
23. Davis RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. *Human Movement Science.* 1991;10:575-587.
24. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. *Journal of Orthopaedic Research.* 1990;8:383-392.
25. Sell TC, House AJ, Abt JP, Huang H-C, Lephart SM. An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Phys Ther Sport.* 2012;13(2):80-86.
26. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of athletic training.* 2005;40(4):305-309.

27. Wrisley DM, Stephens MJ, Mosley S, Wojnowski A, Duffy J, Burkard R. Learning effects of repetitive administrations of the sensory organization test in healthy young adults. *Arch Phys Med Rehabil.* 2007;88(8):1049-1054.
28. Alemdaroglu U. The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. *J Hum Kinet.* 2012;31:149-158.
29. Milgrom C, Finestone A, Eldad A, Shlamkovitch N. Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits. *The Journal of bone and joint surgery. American volume.* 1991;73(7):1041-1043.
30. Palmieri-Smith RM, Lepley LK. Quadriceps Strength Asymmetry After Anterior Cruciate Ligament Reconstruction Alters Knee Joint Biomechanics and Functional Performance at Time of Return to Activity. *Am J Sports Med.* 2015;43(7):1662-1669.
31. Iwai K, Nakazato K, Irie K, Fujimoto H, Nakajima H. Trunk muscle strength and disability level of low back pain in collegiate wrestlers. *Med Sci Sports Exerc.* 2004;36(8):1296-1300.
32. Tsai YS, Sell TC, Smoliga JM, Myers JB, Learman KE, Lephart SM. A comparison of physical characteristics and swing mechanics between golfers with and without a history of low back pain. *J Orthop Sports Phys Ther.* 2010;40(7):430-438.
33. Chu Y, Sell TC, Abt JP, et al. Air assault soldiers demonstrate more dangerous landing biomechanics when visual input is removed. *Military medicine.* 2012;177(1):41-47.
34. Weiss K, Whatman C. Biomechanics Associated with Patellofemoral Pain and ACL Injuries in Sports. *Sports Medicine.* 2015.
35. Hewett TE, Myer GD, Ford KR, et al. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes. *Am J Sports Med.* 2005;33(4):492-501.
36. Munro A, Herrington L, Comfort P. Comparison of landing knee valgus angle between female basketball and football athletes: possible implications for anterior cruciate ligament and patellofemoral joint injury rates. *Phys Ther Sport.* 2012;13(4):259-264.
37. Anderson MK, Grier T, Canham-Chervak M, Bushman TT, Jones BH. Occupation and other risk factors for injury among enlisted U.S. Army Soldiers. *Public Health.* 2015;129(5):531-538.
38. Evans KN, Kilcoyne KG, Dickens JF, et al. Predisposing risk factors for non-contact ACL injuries in military subjects. *Knee Surgery, Sports Traumatology, Arthroscopy.* 2012;20(8):1554-1559.
39. Taanila H, Suni JH, Kannus P, et al. Risk factors of acute and overuse musculoskeletal injuries among young conscripts: a population-based cohort study. *BMC musculoskeletal disorders.* 2015;16(1):104.
40. George SZ, Childs JD, Teyhen DS, et al. Predictors of occurrence and severity of first time low back pain episodes: findings from a military inception cohort. *PLoS One.* 2012;7(2):e30597.
41. Dvorak J, Junge A, Chomiak J, et al. Risk factor analysis for injuries in football players. Possibilities for a prevention program. *Am J Sports Med.* 2000;28(5 Suppl):S69-74.
42. Teyhen DS, Shaffer SW, Butler RJ, et al. What Risk Factors Are Associated With Musculoskeletal Injury in US Army Rangers? A Prospective Prognostic Study. *Clinical Orthopaedics and Related Research.* 2015.
43. Jones BH, Canham-Chervak M, Canada S, Mitchener TA, Moore S. Medical surveillance of injuries in the u.s. Military descriptive epidemiology and recommendations for improvement. *American journal of preventive medicine.* 2010;38(1 Suppl):S42-60.
44. Jones BH, Knapik JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Medicine.* 1999;27(2):111-125.

Physical Readiness and Musculoskeletal Injury Prevention in United States Army Special Forces Operators

Julie Y. Kresta, PhD¹

John P. Abt, PhD, ATC²

Kim Beals, PhD, RD, CSSD³

COL Jeff Morgan, MD⁴

COL Shawn F. Kane, MD⁵

Scott M. Lephart, PhD²

¹Methodist University

Department of Physical Therapy

Fayetteville, NC, USA

²University of Kentucky

College of Health Sciences

Lexington, KY, USA

³University of Pittsburgh

Neuromuscular Research Laboratory

Pittsburgh, PA, USA

⁴Department of the Army

Womack Army Medical Center

Fort Bragg, NC, USA

⁵US Army Special Operations Command

Fort Bragg, NC, USA

Corresponding Author:

John P. Abt, PhD, ATC²

University of Kentucky

College of Health Sciences

Lexington, KY

ABSTRACT

Unintentional musculoskeletal (MSK) injuries continue to be a significant issue for the United States Army Special Operations. There is a need to find ways to identify and modify risk factors to injuries to sustain the careers of Operators as well as to maximize physical performance on job specific tasks. The purpose of this study was to examine the relationship of physical readiness rankings to MSK injury risk factors in US Army Special Forces Operators. A total of 75 Operators participated in this study. Physiological testing included measures of body composition, muscular strength, aerobic capacity and anaerobic power. Individuals also completed a self-reported MSK injury history that covered the span of their military career up to the point of testing. Operators were assigned a physical readiness ranking based on their combined performance on all laboratory testing. Data was then analyzed two separate ways. The first with those ranked in the top 10% being classified as Group 1 with all others in Group 2. The second method was dividing the sample into quintiles based on their overall ranking. Significant differences were noted between groups and quintiles for the majority of performance testing, but not for body composition. Physical readiness ranking did not seem to have a direct impact on injury rates, however the variation within the injury data was quite large, which may have played a role. The present study was one of the first to provide a physiological description of a US Army SF Operator and shed light on possible injury risk factors that can be modified through proper training.

Keywords: Musculoskeletal, Injury, Performance, Fitness, Prevention

INTRODUCTION

Unintentional musculoskeletal injuries continue to be a significant issue for the United States Army Special Operations. Musculoskeletal (MSK) injuries are the most common reasons for medical clinic visits and missed work for Special Forces (SF) Operators (17). This is likely a result of the higher than average physical stress placed on these individuals during training and operations. The literature is incomplete in terms of describing MSK characteristics of SF Operators with previous injuries as well as data to help identify preventable or modifiable factors associated with subsequent injury. The advanced skill level and physical training required of the SF Operator highlights the need to improve suboptimal characteristics for subsequent injury prevention and performance enhancement.

A recent study Teyhen and colleagues (28) sought to identify risk factors associated with MSK injuries in the US Army Ranger population. They utilized various physical measures and health related variables to create a predictive model for MSK injuries. Their model ended up consisting of nonmodifiable factors such as smoking status and history of surgery, as well as modifiable factors such as run time and sit-up performance. They concluded that individuals that presented with more than two modifiable risk factors were at high risk for MSK injuries. This model showed increased prediction accuracy with the increased number of risk factors present. Researchers stated the predictive model approach was to support a risk stratification and tiered approach to injury prevention in this population. (28).

Data from the Armed Forces health Longitudinal Technology Application (AHLTA) database indicated 40% of all clinical diagnoses for US Army 5th SF Group in 2007 were due to MSK injuries (17). This is likely a conservative estimate since Operators may have seen an outside clinic, which would not be represented in AHLTA. Medical charts were reviewed for 108 Naval Special Warfare Operators in addition to self-reported injury history questionnaires of 226 Operators in a study by Lovalekar et al. They reported the average number of MSK injuries per year was 0.32 per subject (16). These studies highlight the need to reduce preventable MSK injuries in the military's elite groups.

It has been well documented that suboptimal physical fitness levels are associated with greater risk for unintentional injuries (11,20,24,25). Knapik et al. examined relationships between physical fitness and injuries in US soldiers participating in basic training. They assessed measures such as body composition, aerobic power and muscular strength. Researchers concluded that lower peak VO₂ increased the potential for sustaining an injury. They did not associate strength or leg power with injury prevalence. However, lower values of muscular endurance were related to increased injury risk (14).

Improving physical fitness typically involves increased physical training to elicit physiological adaptations. Lack of physical activity has been linked to increased injury risk (6,8,9,14,21,27). However, with increased physical activity comes an increased opportunity and risk for MSK injuries. Hauret et al. (7) explained MSK injuries related to increased physical activity are primarily due to cumulative effects of repetitive microtrauma associated with exercise. In addition, conditions like overreaching, overtraining, overuse and over exertion are common in

physical training as well as military occupational duties (7). If both ends of the physical fitness spectrum are associated with increased MSK injury risk, a threshold must exist where physical fitness can be maximized without increasing the risk of injuries (10,21,23,27). In addition, an optimal range of physical fitness or readiness may exist for soldiers where injuries can be prevented, but physical performance is not sacrificed.

Physiological measures such as body composition, aerobic capacity, anaerobic power and muscular strength can be utilized to determine an individual's overall physical fitness or readiness to perform. The present study examined the relationship of physical readiness rankings to MSK injury risk factors in US Army SF Operators.

METHODS

Individuals who volunteered for testing participated in one- or two-day protocol in the University of Pittsburgh Warrior Human Performance Laboratory at Fort Bragg, NC. Prior to testing, all participants read and signed the informed consent in accordance with the University and the Womack Army Medical Center Institutional Review Boards.

Participants

Seventy-five subjects were used for the data analysis. For the main analysis of this data, subjects were arranged into two groups. Group 1 consisted of the top ten percent for overall physical readiness ranking (n=8) and all other subjects were placed into Group 2 (n=67). These subjects had complete data sets for each variable, making it possible to calculate physical readiness rankings. All participants were recruited from the United States Army Special Operations Command. Specific to the present study, Operators assigned to the United States Army Special Forces with an 18 series MOS were used for data analysis. Additional inclusion criteria included: between 18-55 years of age, cleared for full active duty, did not sustain any musculoskeletal injuries in the previous three months, and did not sustain a traumatic brain injury or balance disorder in the previous three months.

Testing protocol

The testing protocol occurred over the course of either one or two days, depending on a variety of factors, namely soldier schedules and testing rigor. Regardless of the number of days, the list of protocols was the same for each participant. Prior to testing, participants were instructed to not perform strenuous exercise for at least 12 hours as well as to not eat or drink anything aside from water for at least 3 hours.

Demographic information was collected that included age, rank, race and years of active duty experience. Laboratory protocols involved testing for body composition, flexibility, muscular strength, aerobic capacity, anaerobic capacity, balance, and a biomechanical analysis of specific tasks. In addition, a self-reported history questionnaire was completed for musculoskeletal injuries sustained from the Begin Active Service Date (BASD) to enrollment in the present study. A musculoskeletal injury was defined as an injury to the musculoskeletal system (e.g. bones, ligaments, muscles, tendons) that resulted in an alteration of tactical activities, tactical training or physical training for a minimum of one day, regardless if medical attention was

sought out. For the purpose of the present paper, only physiology data was analyzed, which included body composition, muscular strength, aerobic capacity and anaerobic capacity. In addition to testing variables, the study analyzed data on retrospective and prospective injuries, which were defined as musculoskeletal injuries sustained in the 12 months prior to enrollment and the 12 months after laboratory testing, respectively. This injury data was obtained through ICD-9 codes from the Armed Forces Health Surveillance Center.

Laboratory Data

Body Composition

Body composition was measured using the Bod Pod® (COSMED USA, Concord, CA). The Bod Pod® is an Air Displacement Plethysmograph (ADP) that uses whole body densitometry to determine body composition. The Bod Pod® was calibrated at the start of each day of testing for the laboratory. Both calibrations and testing were performed in accordance with the manufacturer's instructions. Participants were tested while wearing only spandex shorts and an acrylic swim cap. Thoracic gas volume was estimated for all participants using a predictive equation per the Bod Pod® software. Density was calculated internally as well using the appropriate density equation. Data extracted from this testing included body weight, percent body fat, fat free mass and fat mass. Air displacement plethysmography has been found to be a reliable and valid method for measuring body composition in multiple populations (3,5,18,22).

Muscular Strength

Muscular strength was assessed using the Biodex® System 4 Pro Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY) and participants were stabilized according to the manufacturer instructions for each test. Muscular strength was assessed bilaterally in the shoulder for internal and external rotation, bilaterally in the knees for flexion and extension, as well as trunk flexion extension. All practice and test trials were reciprocal concentric-concentric contractions performed at 60°/s. Three warm-up trials were given at 50% of self-perceived maximum exertion, followed by three warm-up trials at 100% of self-perceived maximum effort. The participant then rested for one minute prior to performing five maximal test repetitions. The average peak torque (Nm) was normalized for body weight and used for data analysis. Muscular strength measured by isokinetic dynamometry has been found to be a valid and reliable method for measuring strength (4,19,26).

Aerobic Capacity

Aerobic capacity was measured using a graded exercise test on the treadmill with oxygen consumption analyzed using the True One® 2400 System (Parvo Medics, Sandy, UT). The device was calibrated prior to each test. The protocol was a modified Astrand that was based on the participant's best effort two-mile run time. Two-miles is a common distance for many soldiers since that is the distance of the run portion for the common Army Physical Training Test that must be taken biannually. The protocol involved a five minute warm-up at 65% of the individual's two mile run pace. The speed would then immediately increase to 85% and remain constant for the duration of the test. The treadmill grade would increase by 2% every three minutes of the testing phase beginning at 0%. The test would continue until the participant

reached volitional fatigue. Upon completion, the treadmill was immediately entered into a cool-down phase that was set to 2.5mph and 0% grade for 3 minutes.

Oxygen consumption (VO_2) was analyzed in 15 second increments with the average of the final minute calculated for each stage of exercise. Aerobic capacity was determined by the participant achieving at least two of the following three criteria: 1) Post-test blood lactate ≥ 8.0 ; 2) maximal heart rate within 10 bpm of the age-predicted maximal rate; and 3) maximal Respiratory Exchange Ratio (RER) ≥ 1.08 . In addition, a plateau in VO_2 was reached at the end of the test, despite an increase in exercise intensity.

Anaerobic Capacity

Anaerobic capacity was determined by using the Wingate Anaerobic Test on the Velotron® cycle ergometer (RacerMate Inc., Seattle, WA). The ergometer was calibrated prior to each day of testing according to manufacturer directions. The ergometer seat height, handle height and handle distance was adjusted to each individual prior to testing. Participants had a five minute warm-up with 50W of resistance. The test protocol started with 20 seconds at 50W, where the participants were told to gradually increase their cadence. With five seconds remaining, they were instructed to sprint and keep pedaling as fast as possible throughout the subsequent 30 seconds. During this 30 seconds, participants pedaled against an individualized resistance based on their body weight. Peak power (PP) and mean power (MP) were assessed with this test. PP was the highest level of power reached by the individual in the first few seconds of the test, while MP is the overall average in power across the 30 seconds.

Injury Rates

Retrospective and prospective musculoskeletal injury data were obtained through the Armed Forces Health Surveillance Center through ICD-9 codes. All musculoskeletal injuries reported for the 12 months prior to their laboratory testing was classified as retrospective. Alternatively, all injuries reported in the 12 months after laboratory testing were classified as prospective.

Data Analysis

Upon completion of all testing, subjects were assigned ranking scores for each individual test as well as an overall ranking, which was termed Physical Readiness Ranking. For the individual tests, the data was arranged in order from the best score achieved to the worst and ranked in order from one through 75. The overall Physical Readiness Ranking was calculated as the sum of all individual ranks from testing. The data was then sorted from the lowest overall ranking value, which would indicate the best scores, to the highest overall ranking value, indicating the worst scores. Data was then stratified into percentiles at 10% increments and compared to the remaining group. For example, the top 10% of scores was called Group 1, with the remaining datasets considered Group 2.

In addition to the Groups 1 and 2 categories, data was classified into quintiles in terms of physical readiness ranking. The data from each percentile group was looked at in terms of injury rates to determine whether any specific ranking classification was associated with lower prospective injury rates.

For the initial analysis of Groups 1 and 2, non-parametric statistical measures were completed using SPSS (version 22.0; SPSS Inc., Chicago, IL) to analyze the data. Specifically, independent-samples Mann-Whitney U and Kruskal-Wallis tests were run for each variable. Quintile data was analyzed using one-way analyses of variance tests with Tukey's Post-hoc analyses on significant findings. Significance was set at the 0.05 level for all statistical testing.

RESULTS

Participants

As previously mentioned, subjects were placed into one of two groups based on their Physical Readiness Ranking. There was no difference between the groups for height ($p=0.843$), however there was a significant difference for weight and age between groups ($p=0.026$ and $p=0.037$, respectively). Table 1 shows the demographic data for each group depicted as mean \pm SD.

Table 1. Demographic Data

Group	Height (in)	Weight (lbs)	Age (years)
1 (n=8)	70.6 \pm 2.0	172.83 \pm 15.3	28.9 \pm 4.4
2 (n=67)	70.7 \pm 2.2	190.4 \pm 21.5*	32.5 \pm 5.2*

*indicates value of group 2 is significantly greater than group 1.

In addition to examining the data from the highest ranking group compared to all subjects, data was also observed for different percentiles, every 20%. Table 2 shows the demographic data for each quintile group depicted as mean \pm SD.

Table 2. Demographic Data by Physical Readiness Ranking Quintiles

Quintile	Height (in)	Weight (lbs)	Age (years)
Q1 (0-20%, n=15)	70.2 \pm 2.3	194.3 \pm 26.8	35.1 \pm 5.7*
Q2 (21-40%, n=15)	70.8 \pm 2.4	190.9 \pm 17.7	32.5 \pm 5.8
Q3 (41-60%, n=15)	71.4 \pm 2.6	192.8 \pm 26.8	32.7 \pm 4.8
Q4 (61-80%, n=15)	70.6 \pm 1.7	189.4 \pm 15.0	31.1 \pm 4.5
Q5 (81-100%, n=15)	70.2 \pm 1.6	175.3 \pm 15.3	29.2 \pm 4.2

*Indicates mean was significantly greater than Q5.

Body Composition

Group 1 has a significantly lower percent body fat at testing compared to group 2 (12.2 \pm 4.3 and 17.3 \pm 5.5%, respectively, $p=0.011$). As shown in Table 2, group 2 also had a greater body weight compared to group 1. The quintile data analysis for percent body fat showed significant differences between Q5 and Q1 ($p=0.019$) and Q2 ($p=0.002$). Table 3 shows the quintile body fat data depicted as mean \pm SD.

Table 3. Percent Body Data by Physical Readiness Ranking Quintiles

Quintile	Percent Body Fat (%)
Q1	19.7 \pm 7.0*
Q2	18.4 \pm 4.3*
Q3	16.5 \pm 5.7

Q4	16.8 ± 3.8
Q5	12.4 ± 4.0

*Indicates mean was significantly greater than Q5.

Muscular Strength

The average peak torque was calculated from the five repetitions performed on the Biodex, which was then normalized to individual body weight prior to data analysis. Group 1 was a significantly greater than group 2 for right knee flexion (170.0±18.7 and 126.0±19.5 %BW, respectively, p=0.000) and extension (291.1±27.9 and 230.8±40.6 %BW, respectively, p=0.000), right shoulder internal rotation (71.8±11.6 and 58.0±11.3 %BW, respectively, p=0.003) and external rotation (43.2±3.2 and 39.3±6.0 %BW, respectively, p=0.022) and torso flexion (225.6±37.9 and 183.6±32.1 %BW, respectively, p=0.009) and extension (333.0±34.5 and 290.2±68.8 %BW, respectively, p=0.019).

Table 4 shows the quintile data for muscular strength data. There were significant differences reported for each right knee flexion (RKF, p=0.000), right knee extension (RKE, p=0.000), right shoulder internal rotation (RSIR, p=0.000), right shoulder external rotation (RSER, p=0.017), torso extension (TE, p=0.002) and torso flexion (TF, p=0.000). The individuals with the highest ranking (Q5) reported significantly greater scores than the lowest quintile (Q1) in all strength variables measured. For RKF, RFE, RSIR and TF, Q5 was also significantly greater than Q2.

Table 4. Muscular Strength Data by Physical Readiness Ranking Quintiles

Quintile	RKF (%BW)	RFE (%BW)	RSIR (%BW)	RSER (%BW)	TF (%BW)	TE (%BW)
Q1	108.7 ± 16.9* [§]	197.0 ± 28.0* ^{§β}	50.2 ± 8.8* [§]	36.7 ± 5.8*	158.7 ± 24.3* ^{§ β}	244.2 ± 50.6*
Q2	120.2 ± 7.5* [§]	216.6 ± 31.4*	56.1 ± 8.8*	38.5 ± 6.2	172.1 ± 29.3*	284.9 ± 72.7 [§]
Q3	126.0 ± 18.8*	251.8 ± 25.2*	59.6 ± 6.9	38.7 ± 4.8	193.8 ± 34.1	296.9 ± 62.3
Q4	139.0 ± 14.6*	242.8 ± 43.3	62.8 ± 15.9	41.6 ± 5.7	201.4 ± 28.0	335.0 ± 74.4
Q5	159.4 ± 20.6	277.9 ± 38.8	68.7 ± 10.1	43.2 ± 5.3	214.2 ± 30.7	313.1 ± 40.7

*Indicates mean was significantly different than Q5; [§]indicates mean was significantly different than Q4; ^βindicates mean was significantly different than Q3.

Aerobic Capacity

Although not significant, there was a slight trend for VO₂max values towards group 1 values being greater than group 2 (50.4±3.2 and 47.7±4.8 ml/kg/min, respectively, p=0.098). However, when data was analyzed as quintiles, there was a difference in VO₂max between groups (p=0.040), with post hoc analysis identifying Q5 and Q1 (50.7±3.9 and 45.6±4.3 ml/kg/min, respectively, p=0.035) as the location for statistical difference. The raw data for aerobic capacity is presented in Table 5 as mean ± SD.

Table 5. Aerobic Capacity Data by Physical Readiness Ranking Quintiles

Quintile	VO2max (ml/kg/min)
Q1	45.6 ± 4.3*
Q2	47.4 ± 3.8
Q3	47.2 ± 6.3
Q4	49.0 ± 4.1
Q5	50.7 ± 3.9

*Indicates mean was significantly different than Q5

Anaerobic Capacity

There was no significant difference between groups for PP (p=0.280). However, there was a significant difference between groups for MP, with group 1 having greater values than group 2 (9.2±0.7 and 8.3±0.9 W, respectively, p=0.010).

When data was analyzed by quintiles, there were significant differences observed for both MP (p=0.001) and PP (p=0.000). Post-hoc analysis for MP revealed Q5 having greater values than Q1 (p=0.000). For PP, Q5 was significantly greater than both Q1 and Q3, with a trend towards significance for Q4 (p=0.000, 0.009 and 0.071, respectively). Q4 was also significantly greater than Q1 (p=0.006). Table 6 shows the means ± SD for the anaerobic data.

Table 6. Anaerobic Capacity Data by Physical Readiness Ranking Quintiles.

Quintile	Peak Power (W/kgBW)	Mean Power (W/kgBW)
Q1	12.8 ± 1.2	7.6 ± 1.1
Q2	14.0 ± 1.4	8.2 ± 0.9
Q3	13.6 ± 1.2	8.6 ± 0.6
Q4	14.5 ± 1.2	8.5 ± 1.0
Q5	15.2 ± 1.2	9.0 ± 0.6

Injury Rates

Injury rates between groups 1 and 2 were not statistically different from one another for either retrospective (p=0.623) or prospective (p=0.512) injuries. Table 7 shows the raw data for each group with the per person data depicted as mean ± SD.

Table 7. Injury Prevalence by Groups

Group	Retrospective Injuries (total #)	Retrospective Injuries (per person)	Prospective Injuries (Total #)	Prospective Injuries (per person)
1 (n=10)	11	1.1 ± 3.1	17	1.7 ± 4.1
2 (n=67)	80	1.2 ± 2.1	137	2.0 ± 3.5

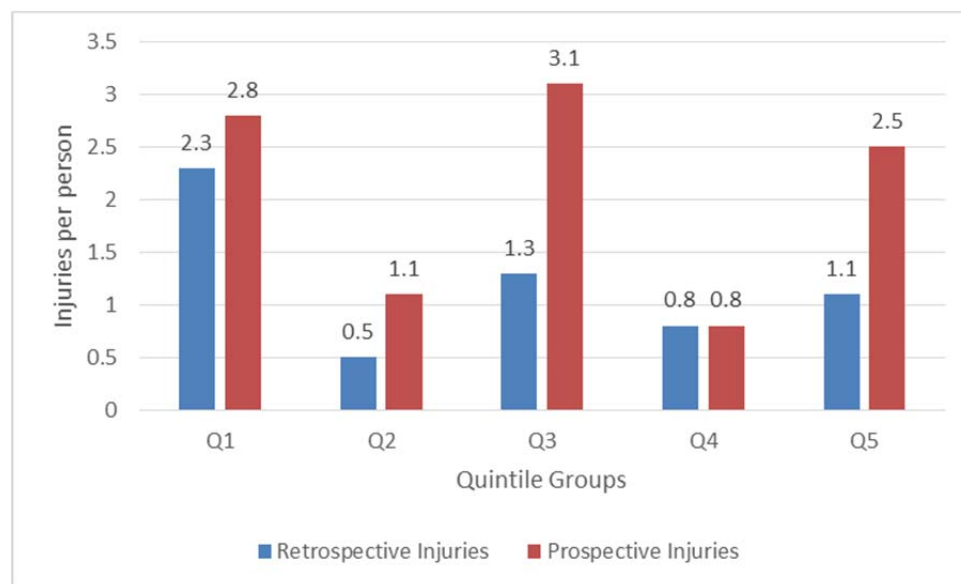
Injury rates per person between quintiles did not reveal any significant differences for retrospective (p=0.195) or prospective (p=0.311) injuries. Table 8 shows the raw data for each quintile with the per person data depicted as mean ± SD. The large standard deviations for each quintile should be noted.

However as Figure 1 shows with the raw totals for prospective injuries, the least number of injuries were associated with Q4 and Q2. The Q4 data is of interest as it had the lowest number of prospective injuries as well as the only group where prospective injuries does not increase from the retrospective injury totals.

Table 8. Injury Prevalence by Quintiles

Quintile	Retrospective Injuries (Total #)	Retrospective Injuries (per person)	Prospective Injuries (Total #)	Prospective Injuries (per person)
Q1	35	2.3 ± 3.3	42	2.8 ± 2.5
Q2	8	0.5 ± 0.6	17	1.1 ± 2.0
Q3	20	1.3 ± 2.3	46	3.1 ± 6.6
Q4	12	0.8 ± 1.3	12	0.8 ± 0.9
Q5	16	1.1 ± 2.3	37	2.5 ± 3.1

Figure 1. Injury Rates by Quintiles



DISCUSSION

The present study serves as an early descriptive report of US SF Operators aimed to provide a physiological database of this population. This study was one of the few to examine risk factors for musculoskeletal injuries in the SF population based on overall physical fitness. Various aspects of physical fitness can be modified through proper training, which would in turn potentially decrease the risk and prevalence of MSK injuries for this specialized population. Physical readiness rankings were calculated for each subject solely based on their performance on the various exercise related testing protocols. From those rankings, various groups were created to examine the data from multiple angles.

The lack of difference observed in body composition for the present study was to be expected and goes along with previous work in military populations. Knapik et al. (14) noted that body composition levels would be relatively uniform in military populations, especially among SF operators, since the population as a whole is fairly similar all experienced the same tactical training programs as well as participated in similar physical training programs in many cases. Individuals at each extreme of the body composition spectrum will most likely not be members of the SF community.

Muscular strength is one area in which multiple differences were found in the data. This is to be expected since the groups were organized based on physical ranking, with multiple strength variables being included in the calculation of overall ranking. What is interesting to note however, is the link between muscular strength values and prospective injuries. Typically, individuals with greater strength values are those that spend more time performing physical training activities, thus also increasing their risk for injury. Values for Q5 were significantly greater than lower quintiles for each strength variable tested. Prospective injuries between quintiles was still not significant when strength variables alone were considered in the rankings ($p=0.420$). However, the SD was very high per group and observed power low at 0.297. Therefore, there may be a trend with strength and injury days, but this was not visible with the present study, most likely due to the large amount of variation in injury days. Previous studies have reported on the relationship between increased strength and decreased injury risk (15).

It has been previously reported that lower $VO_2\text{max}$ values are associated with increased risk for injury (11,25). In the present study, this is somewhat supported by the fewer number of prospective injuries in Q4, which corresponded to the 60-80th percentiles of this population. Comparing this data to the American College of Sports Medicine standards, the Q4 average $VO_2\text{max}$ corresponded to approximately the 80th percentile for healthy males, aged 30-39. Q5 corresponds to only the 85-90th percentiles for the same standards (2). In a previous study, $VO_2\text{max}$ was directly associated with injury prevalence indicating increased $VO_2\text{max}$ levels reporting lower injury incidences for US Army Basic Combat Trainees (13).

The anaerobic data showed most differences with MP instead of PP. This is also to be expected considering the training and tactical exercises and missions performed by Operators. It can be argued that MP is the more applicable anaerobic variable for this population. A previous study on Air Force Combat Controllers measured anaerobic power and capacity with descriptive purposes, similar to the present study. Their results found an average PP of 11.39 W/kg and a MP of 9.27 W/kg, which were both greater than the 90th percentiles (10.89 W/kg and 8.24 W/kg) for males established by Maud and Schultz (#18 from Walker). In the present study, all groups and quintiles scored greater PP values, with an overall average of 14.03 W/kg. For MP, only Q3-Q5 were greater than the 90th percentiles, but all groups were lower than those of the Combat Controllers in the Walker et al., study. (29).

It is not surprising that many performance measures showed differences between the extreme ends of the physical readiness ranking. This study does bring to light the wide range of physiological values obtained on performance tests. Knapik suggests individuals with higher fitness levels sustain fewer injuries in part because they perform tactical activities at a lower

percentage of their maximal capacity (15). In the present study, the most physically fit groups did not sustain fewer injuries, however. Q4 showed some promise of fewer injuries, but with such a large SD, it cannot be concluded from the present data.

The data from the present study showed more prospective musculoskeletal injuries at different locations within the percentile spectrum. At both extremes, there were higher injury rates, which may be expected. Individuals in the higher percentiles that scored better on the physiological tests, which would give them higher rankings are likely to be more active with their exercises. With increased exercise time and more task specific activities, it is likely that an individual is at a greater risk for injury than someone who spends less time performing similar physically stressful tasks. Those individuals who scored lowest on the physiological exams may be expected to have great incidences of injury due to being weaker physically and therefore, while performing physically stressful tasks, may not have the adequate fitness level to be successful, thus leading to potential injury.

It is interesting to note in the present study results that the percentiles in which injury rates were lowest were the 40th and 80th percentiles. The injury rate data was not significant between groups, but it should be noted that the SD was large and calculated power was low at 0.363 for prospective injuries and 0.458 for retrospective injuries. Therefore, these factors may have played a role in the lack of significance between groups for injury rates. Without having detailed information of the subjects' daily activity routine, it is difficult to know the exact reasoning for this trend in injury rates. However, the authors speculate that this may show there is a more ideal physiological range when injury prevention is the target goal.

In a previous study on this population performed by this laboratory, it was determined that of the injuries reported and classified as preventable, 75% occurred during some form of physical training, either organized by command or on their own (1). Therefore, intervening at the trainer's level may be beneficial in reducing preventable injuries. Going back to the present study, focusing on the 80th percentile may give a unique perspective on injury prevention in this highly specialized population. Perhaps there is an optimal range that is not quite at the top that is more ideal for injury prevention. There is a fine line between injury prevention and physical performance. The goal should be to optimize performance while also reducing injury risks.

This study does begin to shed light on possible optimal ranges for physical fitness of an Operator. Trainers can use this information to tailor exercise programs to the individual to bring the Operator's ability to optimal ranges for maximizing performance, but also decreasing risks for MSK injuries.

Nindl et al. (21) previously introduced the concept of a threshold for physical fitness as an injury prevention measure. Authors noted that lack of physical training and activity led to an increased risk for injury, but so did too much training and activity. The present study supports such an idea since the highest scoring individuals reported one of the higher injury rates compared to other quintiles. In addition, the second highest quintile had the lowest injury rate. Therefore, it may be suggested that the optimal range of physical fitness for this population may be around the 80th percentile. This is in reference to injury prevention and further studies need to be done to

determine if this range of physical fitness also corresponds to optimal physical performance on specialized tasks. The Special Forces population is unique in their tasks, therefore performance should be measured specific to their job, unlike those for elite athlete populations.

Future studies may focus on the possible relationships between physical performance on laboratory tests and performance on tactical mission or training simulations. This could help validate the potential for an optimal physical readiness ranking range for this population.

ACKNOWLEDGEMENTS

Supported by the US Army Medical Research and Materiel Command #W81XWH-11-2-0020. Opinions, interpretations, conclusions, and recommendations are those of the authors and not necessarily endorsed by the Department of Defense, Department of the Army, or US Army Special Operations Command.

CONFLICT OF INTEREST

There are no conflicts of interest for any of the authors listed.

REFERENCES

1. Abt JP, Sell TC, Lovalekar MT et al. Injury epidemiology of U.S. Army Special Operations Forces. *Mil Med.* 2014;179(10):1106-12.
2. Arena R. Health-related physical fitness testing and interpretation. In: Pescatello LS, Arena R, Riebe D, Thompson PD, editors. *American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (9th edition)*. Baltimore: Lippincott Williams & Williams; 2014. p. 88.
3. Ballard TP, Fafara L, Vukovich MD. Comparison of Bod Pod and DXA in female collegiate athletes. *Med Sci Sports Exerc.* 2004;36(4):731-5.
4. Drouin JM, Valovich-McLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol.* 2004;91(1):22-9.
5. Fields DA, Goran MI, McCrory MA. Body-composition assessment via air-displacement plethysmography in adults and children: a review. *Am J Clin Nutr.* 2002;75(3):753-67.
6. Gilchrist J, Jones BH, Sleet DA, Kimsey CD. Exercise-related injuries among women: strategies for prevention from civilian and military studies. *MMWR Recomm Rep.* 2000;49(RR-2):15-33.
7. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med.* 2010;38(suppl):S61-S70.
8. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, Frykman PN. Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc.* 1993;25(2):197-203.
9. Jones BH, Bovee MW, Harris JM III, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med.* 1993;21(5):705-10.
10. Jones BH, Cowan DN, Knapik JJ. Exercise, training and injuries. *Sports Med.* 1994;18(3):202-14.
11. Jones BH, Knapik JJ. Physical training and exercise-related injuries: surveillance, research and injury prevention in military populations. *Sports Med.* 1999;27(2):111-25.
12. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med.* 1999;27(5):585-93.
13. Knapik JJ, Sharp MA, Canham ML, Hauret K, Cuthie J. Injury incidence and injury risk factors among US Army Basic Trainees at Ft. Jackson, SC 1998 (including fitness training unit personnel, discharges, and newstarts). Technical Report No. 29-HE-8370-99. Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventative Medicine, 1999.
14. Knapik JJ, Sharp MA, Canham-Chervak M, Hauret K, Patton JF, Jones BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc.* 2001;33(6):946-54.
15. Knapik JJ. The importance of physical fitness for injury prevention: part 1. *J Spec Oper Med.* 2015;15(1):123-7.

16. Lovalekar M, Abt JP, Sell TC, Keenan K, Zimmer A, Lephart SM. Descriptive epidemiology of musculoskeletal injuries in Naval Special Warfare personnel. *Med Sci Sports Exerc.* 2013;45(5s):63-6.
17. Lynch JH, Pallis MP. Clinical diagnosis in a Special Forces group: the musculoskeletal burden. *J Spec Oper Med.*
18. Malavolti M, Battistini NC, Dugoni M, Bagni B, Pietrobelli A. Effect of intense military training on body composition. *J Strength Cond Res.* 2008;22(2):508-8.
19. McCleary RW, Anderson JC. Test-retest reliability of reciprocal isokinetic knee extension and flexion peak torque measurements. *J Athl Train.* 1992;27(4):362-5.
20. Molloy JM, Feltwell DN, Scott SJ, Niebuhr DW. Physical training injuries and interventions for military recruits. *Mil Med.* 2012;177(5):553-8.
21. Nindl BC, Williams TJ, Deuster PA, Butler NL, Jones BH. Strategies for optimizing military physical readiness and preventing musculoskeletal injuries in the 21st century. *US Army Med Dep J.* 2013; Oct-Dec:5-23.
22. Noreen EE, Lemon PW. Reliability of air displacement plethysmography in a large, heterogeneous sample. *Med Sci Sports Exerc.* 2006;38(8):1505-9.
23. Pollock ML, Gettman LR, Milesis CA, Bah MD, Durstine L, Johnson RB. Effects of frequency and duration of training on attrition and incidence of injury. *Med Sci Sports.* 1977;9(1):31-36.
24. Pollock ML, Gaesser GA, Butcher JD, et al: American College of Sports Medicine position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in adults. *Med Sci Sports Exerc.* 1998;30(6):975-91.
25. Rauh MJ, Macera CA, Trone DW, Shaffer RA, Brodine SK. Epidemiology of stress fracture and lower-extremity overuse injury in female recruits. *Med Sci Sports Exerc.* 2006;38(9):1571-7.
26. Sole G, Hamrén J, Milosavljevic S, Nicholson, Sullican SJ. Test-retest reliability of isokinetic knee extension and flexion. *Arch Phys Med Rehabil.* 2007;88(5):626-31.
27. Technical Bulletin Med 592: Prevention and Control of Musculoskeletal Injuries Associated with Physical Training. Washington, DC: US Dept of the Army; [cited 2011 May]. Available from: http://armypubs.army.mil/med/dr_pubs/dr_a/pdf/tbmed592.pdf.
28. Teyhen DS, Shaffer SW, Butler RJ, et al. What risk factors are associated with musculoskeletal injury in US Army Rangers? A prospective prognostic study. *Clin Orthop Relat Res.* 2015;473(9):2948-58.
29. Walker TB, Lennemann LM, McGregor JN, Zupan MF. Physiological and psychological characteristics of successful combat controller trainees. *J Spec Oper Med.* 2010;11(1):39-47.

Injury Epidemiology of US Army Special Operations Forces

Timothy Sell, John Abt, Mita Lovalekar, Tony Bozich, Peter Benson, Jeffrey Morgan, Scott Lephart FACSM

Musculoskeletal injuries (MSIs) have long been a problem in general purpose forces, yet anecdotal evidence provided by medical, human performance, and training leadership suggests MSIs are also a readiness impediment to Special Operations Forces (SOF). The advanced tactical and physical requirements of SOF and fiscal implications, including direct medical costs and manpower, of training SOF highlight the importance of mitigating MSIs. **Purpose:** To describe the injury epidemiology of SOF utilizing self-reported injury histories. **Methods:** A total of 106 SOF were enrolled (Age: 31.7 ± 5.3 years, Height: 179.0 ± 5.5 cm, Mass: 85.9 ± 10.9 kg) as a part of a comprehensive biomechanical, musculoskeletal, physiological, and nutritional laboratory test protocol. Self-reported musculoskeletal injury data were collected for one year prior to the date of laboratory testing and filtered for total injuries and those with the potential to be preventable based on injury type, activity, and mechanism. **Results:** The frequency of MSIs was 24.5 injuries/100 subjects/year for total injuries and 18.9 injuries/100 subjects/year for preventable injuries. The incidence of MSIs was 20.8 injured subjects/100 subjects/year for total injuries and 16.0 injured subjects/100 subjects/year for preventable injuries. Preventable MSIs comprised 76.9% of total injuries. The knee and shoulder were the most common reported locations for total injuries (each 23.1%) and preventable injuries (each 25.0%). Preventable MSIs were classified as 60% acute, 35% chronic/overuse, and 5.0% other/unknown. Physical training (PT) was the most reported activity for total injuries (PT Command Organized: 46.2%, PT Non Command Organized: 7.7%, PT Unknown: 3.8%) and preventable injuries (PT Command Organized: 60.0%, PT Non Command Organized: 10.0%, PT Unknown: 5.0%). **Conclusions:** MSIs impede optimal physical readiness and tactical training in the SOF community. The data suggest that a significant proportion of MSIs are classified as preventable and may be mitigated with human performance programs.

Opinions, interpretations, conclusions, and recommendations are those of the author and not necessarily endorsed by the Department of Defense, US Army, or US Army Special Operations Command.

Supported by USAMRMC #W81XWH-11-2-0020

Dietary Protein Intake and Protein Supplement Use of United States Army Special Operations Command Operators

Rachel A. Baker, Kim Beals, Matthew E. Darnell, John P. Abt, Timothy C. Sell, Shawn F. Kane, Jeffrey S. Morgan, Peter J. Benson, Scott M. Lephart,

University of Pittsburgh, Pittsburgh, PA, US Army Special Operations Command, Fort Bragg, NC

The desire to gain lean muscle mass is a common body composition goal of United States Army Special Operations Command (USASOC) Operators. Sports nutrition guidelines recommend dietary protein intake of 1.2-1.7g/kg/day for resistance-trained athletes. In accordance with the Department of Defense's Operation Supplement Safety campaign, Dietitian's advocate Operators take a "food first" approach instead of using dietary supplements. **PURPOSE:** To assess the number of USASOC Operators taking protein supplements and whether or not protein needs are met through diet alone. **METHODS:** A total of 91 USASOC Operators (age: 29.1±6.5yrs, height: 70.5±2.8cm, weight: 81.4±9.7kg, body fat: 15.9±5.3%) completed a 24-hr dietary recall and nutrition history questionnaire. Dietary intake was analyzed using an automated self-administered 24-hour diet recall. **RESULTS:** Protein intake was 137±59g/day. Protein requirements were met or exceeded through diet alone in 79% of Operators, of these, 42% reported protein supplement use. Dietary protein recommendations were not met in 21% of Operators, of these 42% indicated taking a protein supplement. **CONCLUSION:** The majority of USASOC Operators are consuming adequate dietary protein to promote lean muscle gains with strength-training. Exceeding the recommended range for protein, has not been shown to promote further gains in muscle size/strength, and may lead to undesirable weight gain if caloric needs are surpassed. Consuming protein supplements raises safety concerns, potentially exposing Operators to harmful ingredients in unknown amounts. Nutrition education focused on high quality protein foods properly timed throughout the day may decrease reliance on protein supplements and provide a safer alternative. Supported by ONR # W81XWH-11-2-0020.

Residual Impact of Previous Injury on Musculoskeletal Characteristics in Special Forces Soldiers

Shawn F. Kane, FACSM, John P. Abt, Julie Kresta, James Bakey, Jeffrey J. Parr, Timothy C. Sell, Scott M. Lephart, FACSM

University of Pittsburgh, Pittsburgh, PA, US Army Special Operations Command, Fort Bragg, NC

Musculoskeletal injuries are a significant burden to US Army Special Operations Command (USASOC). The advanced tactical skill level and physical training required of USASOC Special Forces Soldiers highlight the need to improve suboptimal musculoskeletal characteristics, particularly following injury to reduce the likelihood of suffering a recurrent preventable injury.

PURPOSE: To identify the residual impact of previous injury on musculoskeletal characteristics. **METHODS:** A total of 106 Special Forces Soldiers were enrolled in this study. Isokinetic strength of the knee, shoulder, and back and flexibility of the shoulder and hamstrings were assessed as part of a comprehensive human performance protocol. A self-reported musculoskeletal injury history was obtained from the time of enlistment to that of laboratory testing. Subjects were stratified based on knee, shoulder, or back injury and analyzed separately. **RESULTS:** For the knee injury analysis, no significant strength or flexibility differences existed ($p > 0.05$). For the shoulder injury analysis, internal rotation strength of the healthy subjects was significantly higher (60.8 ± 11.5 %BW) compared to the injured (54.5 ± 10.5 %BW, $p = 0.05$) and uninjured limbs (55.5 ± 11.3 %BW, $p = 0.014$) of the injured group. The external rotation/internal rotation strength ratio was significantly lower in the healthy subjects (0.653 ± 0.122) compared to the injured (0.724 ± 0.121 , $p = 0.026$) and uninjured (0.724 ± 0.124 , $p = 0.018$) limbs of the injured group. Posterior shoulder tightness was significantly different between the injured and uninjured limb of the injured group (Injured: $111.6 \pm 9.4^\circ$, Uninjured: $114.4 \pm 9.3^\circ$, $p = 0.008$). For the back injury analysis, no significant strength differences were demonstrated between the healthy and injured groups ($p > 0.05$). **CONCLUSION:** Few physical differences existed between Soldiers with prior knee or back injury suggesting restoration of strength and flexibility. For differences that existed in the shoulder, rehabilitation/human performance training should target specific suboptimal musculoskeletal characteristics to prevent the recurrence of injury and allow return to unrestricted training and operations.

Opinions, interpretations, conclusions, and recommendations are those of the author and not necessarily endorsed by the Department of Defense, US Army, or US Army Special Operations Command. Supported by USAMRMC #W81XWH-11-2-0020

Identification of Asymmetrical and Suboptimal Agonist/Antagonist Strength in a Cohort of Special Forces Soldiers

John P. Abt, Shawn Eagle, Julie Y. Kresta, James F. Bakey, Timothy C. Sell, Shawn F. Kane, FACSM, Scott M. Lephart, FACSM

University of Pittsburgh, Pittsburgh, PA, US Army Special Operations Command, Fort Bragg, NC

Unilateral strength training has gained significant interest within the military as an adopted training principle. Theoretically, unilateral strength training should promote similar bilateral and unilateral agonist/antagonist synergy by limiting the dominant limb's support of total workload.

PURPOSE: To identify asymmetrical and non-synergistic strength in a cohort of Special Forces Soldiers. **METHODS:** A total of 86 Special Forces Soldiers participated. Isokinetic strength of the knee and shoulder was assessed as part of a comprehensive human performance protocol. The proportion of individual bilateral differences ($> 10\%$ difference) was calculated for each joint and variable. The proportion of insufficient strength ratios was calculated based on established normative clinical data. **RESULTS:** Individual bilateral strength differences were identified in 45.1% of subjects for knee flexion and 43.1% for knee extension. An insufficient knee flexion/extension ratio was identified in 43.1% of Soldiers. Individual bilateral strength differences were identified in 45.3% of subjects for internal rotation and 35.8% for external rotation. Insufficient external rotation/internal rotation strength ratios were identified in 35.8-49.1% of Soldiers. **CONCLUSION:** A high proportion of Soldiers demonstrated bilateral asymmetry $> 10\%$. This threshold has been previously identified as a risk factor for musculoskeletal injury and may compromise physical readiness. Soldiers presenting with musculoskeletal asymmetries and/or insufficient strength ratios may be predisposed to musculoskeletal injury. Both of these scenarios may limit physical readiness at the individual and unit level. Individuals demonstrating asymmetrical or insufficient strength ratios may benefit from unilateral strength training.

Opinions, interpretations, conclusions, and recommendations are those of the author and not necessarily endorsed by the Department of Defense, US Army, or US Army Special Operations Command. Supported by USAMRMC #W81XWH-11-2-0020